Georgetown University Law Center
Scholarship @ GEORGETOWN LAW

2024

Blinded by the Light: Resolving the Conflict Between Satellite Megaconstellations and Astronomy

David A. Koplow
Georgetown University Law Center, koplow@law.georgetown.edu

This paper can be downloaded free of charge from:
https://scholarship.law.georgetown.edu/facpub/2598

Vanderbilt Journal of Transnational Law, Vol. 57, Pp. 219-299.

This open-access article is brought to you by the Georgetown Law Library. Posted with permission of the author.
Follow this and additional works at: https://scholarship.law.georgetown.edu/facpub

Part of the Air and Space Law Commons, International Law Commons, Military, War, and Peace Commons, and the National Security Law Commons

Blinded by the Light: Resolving the Conflict between Satellite Megaconstellations and Astronomy

David A. Koplow*

Abstract

The sudden emergence of large constellations of small satellites in low altitude orbits represents one of the most dramatic contemporary innovations in outer space. Promising low-cost, low-latency global communications and spectacular capacities for remote sensing of the Earth, these satellites will soon number in the tens of thousands, sponsored by diverse corporations and countries around the world. But this proliferation of spacecraft comes at a steep cost in unavoidable interference with ground-based astronomy: as the satellites overfly the observatories, they block the views of remote objects and phenomena, leaving obliterating white streaks on the collected imagery, and obscuring access to troves of vital data from distant sources of cosmic light and radio waves.

To date, the world has been proceeding on the implicit assumption that the law of outer space essentially licenses the satellite operators to proceed however they wish in this matter, with little required consideration for the losses inflicted upon astronomy and the myriad scientific missions. There have been some modest, voluntary efforts at mitigation of the interference effects, but nothing sufficient or reliable has been effectuated.

This Article describes the incipient clash between satellite megaconstellations and astronomy, assesses the relevant international and domestic legal authorities, and proposes compromise solutions to mitigate the damage. Overall, the thesis is that a better balance—meaningfully informed by the Outer Space Treaty—must be struck

---

* Scott K. Ginsberg Professor of Law, Georgetown University Law Center. The author gratefully thanks Natasha H. Sarna for her superb, thorough research assistance in support of this Article, and the following colleagues, friends, and experts who graciously provided input and feedback during its preparation: Rudolf Albrecht, Steven Battel, James M. Bauer, Aaron C. Boley, Michael Byers, Michael R. Cannon, Patricia Cooper, Christopher G. De Pree, Robin J. Frank, David Goldstein, Laura Grego, Peter Hulsroj, Raymond Jeanloz, Christopher D. Johnson, Lindley Johnson, Steven M. Kahn, Josef S. Koller, Rob R. Landis, Paul B. Larsen, Daniel D. Mazanek, Steven Mirmina, Rafael Moro-Aguilar, Charles Lee Mudd Jr., Charles D. Norton, Caryn Schenewerk, Philip G. Schrag, Kai-Uwe Schrogl, Louis Michael Seidman, Alan H. Shaw, Mark A. Skinner, Gabriel W. Swiney, John L. Tonry, Thomas Tycz, Sheldon Wasik, and Andrew Williams.

between these competing types of space activities, without ceding to either a comprehensive right to proceed in disregard of the key functions of the other.

TABLE OF CONTENTS

I. INTRODUCTION

What should happen when a new user of a scarce resource disrupts the longstanding patterns of prior users in exploiting that same resource—do the early actors enjoy some type of vested rights requiring compensation or adjustment, or may the newcomer proceed unabated without consideration for the established practices? Does it matter whether the new uses will be fabulously remunerative and provide immense value to people around the globe, while the prior applications are "merely" scientific in nature, offering long-term and diffuse benefits? Does it matter whether the resource in question may be characterized as constituting a "global commons," devoid of traditional property ownership rights and even of state sovereignty?

Those esoteric political, economic, and technical puzzles are currently unfolding in an unfamiliar locale, outer space—a resource that may seem infinitely large, but that in fact engages sharply competitive interests between traditional ground-based astronomy versus the purveyors of megaconstellations of communications and remote sensing satellites. The observatories require a dark and quiet night sky for the collection of images and other scientific data from afar; satellite companies are in the process of sending thousands of commercial spacecraft into Low-Earth Orbit, threatening to obscure the pristine views and sounds of the cosmos and to render much astronomical research useless. In short, when the emerging massive clusters of satellites substantially interfere with the operation of existing and planned observatories, how should that conflict be resolved?

This Article explores that imminent dilemma, identifying the physical facts that make these rivalrous uses so problematic, scrutinizing the international and domestic law claims that partisans on each side can assert, and proposing a path toward reconciliation.

The Article is organized as follows. After this Introduction, Part II discusses the dazzling world of astronomy, describing the goals and benefits of that activity, the diverse facilities that participate, and the conditions necessary for success. It underscores the special long-term contributions that astronomy makes to humanity, as well as the surprising fragility of the enterprise.

Part III then addresses the proliferation of small satellites, currently numbering in the thousands and projected to surge by another order of magnitude in the coming decade. It explains the great boon this New Space revolution promises for both the public and private sectors, in expanding global access to low-latency broadband communications, reconnaissance, and other vital services.

Next, Part IV presents the heart of the problem, explaining the technological incompatibility between ground- or space-based astronomy and large constellations of satellites, as the incessant overflights leave streaks of blinding light on telescopes' imagery and other products, obscuring access to critical space data. It describes the partial measures of accommodation that have been offered by some space companies to date, as well as addressing the inadequacy of other available mitigations, and it anticipates further divergences of interests in the coming years.

Part V turns to the law, presenting the endowment of domestic and international rights and obligations, principally emanating from the foundational 1967 Outer Space Treaty (OST),[1] ·that are incumbent upon all space actors. These legal relationships are not adequately detailed in the treaty or in the subsequent state practice, and the rest of the legal infrastructure for outer space provides inadequate clarity regarding the various parties' legal starting points or the methods for ensuring peaceful, mutually advantageous compromise outcomes. But there are some powerful legal penumbras nonetheless.

---

1. *See* Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, Jan. 27, 1967, 18 U.S.T. 2410, 610 U.N.T.S. 205 [hereinafter OST].

Part VI proposes some possibilities and recommendations about balancing the competing interests. It acknowledges that there is no perfect solution here—and that this is a rare situation in which financial compensation alone would be insufficient, in view of the potential for long-term, essentially irreversible damage—but posits that each side should undertake some sacrifices for the benefit of the other.

Finally, the Conclusion offers some closing reflections.

Overall, the thesis of this Article is that the world should not continue to blithely assume that the newfound interests of megaconstellation satellite operators should automatically prevail in this clash; the rights of the astronomy community must be respected too. The bargaining to reconcile the competing legitimate stakes will not be easy, and it may be fought in political as well as legal forums, and globally as well as inside the United States.

II. ASTRONOMY

A. *Applications of Astronomy*

Astronomy is a most venerable art and science. Humans, both ancient and modern, have gazed into the firmament with awe, deriving both inspiration and useful knowledge by observing the oscillating pattens among the stars.[2] Through the millennia, meticulous records

---

2. *See* G.A. Res. 62/200, (Dec. 19, 2007) (declaring 2009 to be the International Year of Astronomy, noting that "astronomy is one of the oldest basic sciences and that it has contributed and still contributes fundamentally to the evolution of other sciences and applications in a wide range of fields," and recognizing that "astronomical observations have profound implications for the development of science, philosophy, culture and the general conception of the universe."). The deep-seated religious and poetic values from stargazing are largely beyond the scope of this Article, but they continue to exert powerful influences on humans and communities. *See, e.g.*, NOIR LAB, AURA, & AM. ASTRONAUTICAL SOC'Y, SATCON2 WORKING GROUP REPORTS 102 (Connie Walker & Jeffrey Hall eds., 2021) (addressing indigenous communities' perspectives about the diminishing darkness of the night sky) [hereinafter SATCON2]; AARON BOLEY, SAMANTHA LAWLER, PAULINE BARMBY, JAMES DI FRANCESCO, ANDREW FALLE, JENNIFER HOWSE & JJ KAVELAARS, REPORT ON MEGA-CONSTELLATIONS TO THE GOVERNMENT OF CANADA AND THE CANADIAN SPACE AGENCY 16 (2021) https://arxiv.org/abs/2104.05733 [https://perma.cc/JW39-4T9G] (archived Nov. 15, 2023) (discussing indigenous rights and practices regarding night skies); U.N. OFF. FOR OUTER SPACES AFFS., INT'L ASTRONOMICAL UNION, INSTITUTO DE ASTROFÍSICA DE CANARIAS, NOIR LABS & EUR. S. OBSERVATORY, DARK AND QUIET SKIES FOR SCIENCE AND SOCIETY 137–39 (Connie Walker & Piero Benvenuti eds., 2021) [hereinafter 2021 Workshop]; Aparna Venkatesan, James Lowenthal, Parvathy Prem, & Monica Vidaurri, *The Impact of Satellite Constellations on Space as an Ancestral Global Commons*, 4 NATURE ASTRONOMY 1043, 1043 (2020); CIPRIANO MARIN, STARLIGHT: A COMMON HERITAGE 449 (Cipriano Marin & J. Jafar eds., 2009) (introducing the Starlight Initiative to preserve "values associated with the night sky and the general right to observe the stars"); Ciara Finnegan, *Indigenous Interests in Outer Space: Addressing the Conflict of Increasing Satellite Numbers with Indigenous Astronomy Practices*, MULTIDISCIPLINARY DIGIT. PUBL'G INSTIT. 1, 1 (2022).

about the progression of celestial bodies have promoted multiple civilizations' critical efforts at navigation, agriculture, and calendaring.[3]

Today, astronomy serves multiple social purposes, both arcane and quotidian. Near the top of the list of contributions would be "pure science"—the exploration of the universe, attempting to capture the secrets of the origins and evolution of all matter and the future of our planet.[4] Peering into the void for vanishingly small electromagnetic signatures is painstaking work, requiring the closest attention to minute and transient signals, but it can generate jaw-dropping discoveries. Astronomers have earned multiple Nobel Prizes for contributions such as unlocking new understandings about the Big Bang, black holes, and other ethereal phenomena.[5] All participants would agree that there is much more to be found, as astronomy probes regions ever more distant, ancient, and obscure, and as it generates spin-off technologies that flow across the scientific and economic spectrum.[6]

---

3. *See* U.N. OFFICE FOR OUTER SPACES AFFS., INT'L ASTRONOMICAL UNION, INSTITUTO DE ASTROFÍSICA DE CANARIAS, NOIR LABS & EUR. S. OBSERVATORY, DARK AND QUIET SKIES FOR SCIENCE AND SOCIETY 92–117 (2020) [hereinafter 2020 Workshop] (discussing the health importance for humans, plants, and animals of adequate darkness at night); Andy Williams, *Five Reasons Why Astronomy Is Important to Our Future in Space*, LINKEDIN (June 21, 2019), https://www.linkedin.com/pulse/five-reasons-why-astronomy-important-our-future-space-andy-williams [https://perma.cc/J4P5-FTZ8] (archived Sept. 12, 2023); *see generally* Marissa Rosenberg, Pedro Russo, Georgia Bladon, & Lars Lindberg Christensen, *Astronomy in Everyday Life*, 14 CAP J. 30 (2014); Eric Betz, *How Does Astronomy Affect Your Day-to-Day Life?*, ASTRONOMY (Apr. 3, 2020), https://www.astronomy.com/space-exploration/how-does-astronomy-affect-your-day-to-day-life/ [https://perma.cc/RKX8-2F62] (archived Sept. 14. 2023) (discussing important spin-off technologies derived from astronomy).

4. *See* ASTRONOMY AND ASTROPHYSICS IN THE NEW MILLENNIUM 3, 18, 52 (Nat'l Rsch. Council ed., 2001) [hereinafter NEW MILLENNIUM] (identifying the key goals of astronomy and raising the foundational questions that astronomy seeks to answer),

5. 2020 Workshop, *supra* note 3, at 35 (noting that radio astronomy alone has won four Nobel Prizes since 1974).

6. Rosenberg, Russo, Bladon & Christenson, *supra* note 3, at 31; INT'L TELECOMM. UNION, HANDBOOK ON RADIO ASTRONOMY 4–8 (Radiocommunication Bureau ed., 3rd ed. 2013) [hereinafter HANDBOOK] (describing multiple contributions from radio astronomy to scientific and commercial applications); *see generally Impact of Satellite Constellations on Optical Astronomy and Recommendations Toward Mitigations*, NOIR LAB, AURA, & AM. ASTRONAUTICAL SOC'Y 1, 14 (2020); *Appendices to "Impact of Satellite Constellations on Optical Astronomy and Recommendations Toward Mitigations"*, NOIR LAB, AURA, & AM. ASTRONAUTICAL SOC'Y 1, 65 (2020) [hereinafter SATCON1] (surveying nine genres of sky observations that could be impacted by satellite constellations); *Recommendations to Keep Dark and Quiet Skies for Science and Society*, ¶3, U.N. Doc. A/AC.105/C.1 (Apr. 19, 2023) [hereinafter 2021 CRP] (asserting that the knowledge acquired from astronomy leads to broadly-applicable technical progress, so "it is therefore in the interest of many sectors of society to enable astronomy and cosmology to benefit from access to the sky, free of anthropogenic interference"); NEW

Of course, astronomy also provides an essential operational capability for all robotic and crewed space exploration programs. For example, the forthcoming renewal of the human presence on the Moon and the extension of the missions to Mars could not proceed without the knowledge and constant guidance gleaned from astronomy.[7]

Another prominent direct application of astronomy lies in the realm of "planetary defense"—the effort to detect, track, and characterize potentially hazardous asteroids and other celestial bodies that might someday fly on a collision course with Earth. There are thousands of such behemoths out there, and more are discovered daily—but despite persistent efforts, the task of finding all those that are massive and proximate enough to be characterized as potential "city killers" will require many more years of dedicated searching.[8]

Astronomy is also engaged in the search for extraterrestrial life, a classic example of a program that might proceed for many years with little or nothing of interest to report but that might someday provide one of the most profound discoveries in human history.[9]

MILLENNIUM, *supra* note 4, at 137–54 (summarizing the benefits to the nation from astronomy).

7. Elizabeth Zubritsky, *How Two Ground-based Telescopes Support NASA's Cassini Mission*, NASA (Sept. 11, 2017), https://www.nasa.gov/feature/goddard/2017/ground-based-telescopes-support-cassini [https://perma.cc/6WR6-3LHJ] (archived Sept. 12, 2023); Williams, *supra* note 3; *Deep Space Network*, NASA, https://www.jpl.nasa.gov/missions/dsn [https://perma.cc/8LCL-4MAF] (archived Sept. 12, 2023); Briley Lewis, *The Most Distant Spacecraft in the Solar System – Where Are They Now?*, SPACE.COM (Dec. 30, 2022), https://www.space.com/most-distant-spacecraft-voyagers-new-horizons [https://perma.cc/F764-8PVL] (archived Sept. 26, 2023) (describing the array of radio telescopes that receive faint signals from nearly 50-year-old Voyager spacecraft exploring space 14 billion miles away).

8. *See Planetary Defense*, NASA, https://www.nasa.gov/planetarydefense/overview [https://perma.cc/564R-XAXJ] (archived Sept. 12, 2023) (describing the tasks of the NASA office responsible for leading the planetary defense efforts); *Space Mission Planning Advisory Group*, EUR. SPACE AGENCY, https://www.cosmos.esa.int/web/smpag [https://perma.cc/RP8J-NMEV] (archived Sept. 12, 2023) (introducing the primary international entity undertaking to prepare a coordinated global response to the threat of a near-Earth object); *see* INT'L ASTEROID WARNING NETWORK, https://iawn.net/ [https://perma.cc/87WQ-P43J] (archived Sept. 12, 2023); 2021 Workshop, *supra* note 2, at 119–20 (emphasizing the role of astronomy in planetary defense); Am. Astronautical Soc'y & Inst. of Physics Publ'g, *Apophis Planetary Defense Campaign*, 3 PLANETARY SCI. J. 1, 3–4 (2022) (describing an international planetary defense exercise in which dozens of observations from ground-based and space-based telescopes, using visible, radar, and other technologies, tracked a hypothetical potentially hazardous asteroid).

9. FRANCIS LYALL & PAUL B. LARSEN, SPACE LAW: A TREATISE 483–507 (Routledge, Taylor & Francis Group. eds., 2d ed. 2018) (describing search for extraterrestrial intelligence); HANDBOOK, *supra* note 6, at 121–28 (discussing radio astronomy and the search for extraterrestrial intelligence); *Finding Artificial Signals*, BERKLEY SETI RSCH. CTR., https://seti.berkeley.edu/listen/research.html [https://perma.cc/F3QW-9342] (archived Sept. 26, 2023) (describing the use of radio and optical telescopes in the search for extraterrestrial life); Seth Shostak, *SETI and the*

Of greater immediate application is astronomy's essential input to "space situational awareness," the effort to monitor all the "stuff" in space—operational and dead satellites, spent rocket bodies and other mission detritus, and miscellaneous pieces of natural and human-created debris. Traveling at immense orbital speeds, this material poses critical dangers; a collision with even a small fragment could prove fatal for any spacecraft. By continuously tracking some 25,000 of the larger pieces, it is possible to provide timely warnings about anticipated conjunctions, to empower evasive maneuvers or other defensive measures.[10] In the future, a more comprehensive global program of "space traffic management" must evolve to regularize the

---

Allen Telescope Array (ATA), SETI INST. (July 2021), https://www.seti.org/seti-allen-telescope-array-ata [https://perma.cc/A939-NYDN] (archived Sept. 12, 2023); Michael Garrett, *SETI: New Signal Excites Alien Hunters – Here's How We Could Find Out If It's Real*, THE CONVERSATION (Jan. 4, 2021), https://theconversation.com/seti-new-signal-excites-alien-hunters-heres-how-we-could-find-out-if-its-real-152498 [https://perma.cc/3SP9-LM79] (archived Sept. 12, 2023)*; see also* Keith Kloor, *Paranormal Activity Why is Harvard University Astrophysicist Avi Loeb Working with Ardent UFO?*, SCI. (Jan. 28, 2002), https://www.science.org/content/article/why-is-harvard-astrophysicist-working-with-ufo-buffs [https://perma.cc/YV55-MQ22] (archived Sept. 18, 2023) (reporting use of astronomy in the investigation of unidentified flying objects).

10. Brian Weeden, *Space Situational Awareness Fact Sheet*, SECURE WORLD FOUND (2017), https://swfound.org/media/205874/swf_ssa_fact_sheet.pdf [https://perma.cc/57QK-EBBL] (archived Sept. 18, 2023) (describing use of ground-based and space-based radars, optical telescopes, and other instruments for monitoring objects in space); BRIAN WEEDEN, PAUL CEFOLA & JAGANATH SANKARAN, GLOBAL SPACE SITUATIONAL AWARENESS SENSORS 1–3 (2010); *see Orbital Debris Quarterly News*, 26 NASA, no. 2, 2022, at 1, 12 (tallying 25,209 catalogued objects in orbit, tracked by U.S. Space Surveillance Network); JASON THE MITRE CORP., THE IMPACTS OF LARGE CONSTELLATIONS 85–112 (2020) [hereinafter JASON] (discussing danger of satellite collisions); 2021 Workshop, *supra* note 2, at 19; Adam P. Wilmer & Robert A. Bettinger, *Beyond the High Ground: A Taxonomy for Earth-Moon System Operations*, 1 AIR & SPACE OPERATIONS REV. 13, 13 (2022) (discussing "space domain awareness," formerly known as "space situational awareness"); *see generally* HANDBOOK, *supra* note 6, at 8; *Space Debris by the Numbers*, EUR. SPACE AGENCY, https://www.esa.int/Space_Safety/Space_Debris/Space_debris_by_the_numbers [https://perma.cc/K7UM-KZGB] (archived Sept. 12, 2023) (counting about 31,740 pieces of tracked debris in space and millions of smaller, untracked pieces); U.S. GOV'T ACCOUNTABILITY OFF., LARGE CONSTELLATIONS OF SATELLITES MITIGATING ENVIRONMENTAL AND OTHER EFFECTS 38–52 (2022) [hereinafter Technology Assessment]; U.S. GOV'T ACCOUNTABILITY OFF., SPACE SITUATIONAL AWARENESS: D.O.D. SHOULD EVALUATE HOW IT CAN USE COMMERCIAL DATA (Apr. 24, 2023), https://www.gao.gov/products/gao-23-105565 [https://perma.cc/Q4MD-BNTW] (archived Sept. 18, 2023) (describing radars and optical telescopes used by the Department of Defense to monitor space traffic); Jingrui Zhang, Yifan Cai, Chenbao Xue, Zhirun Xue & Han Ca, *LEO Mega Constellations: Review of Development, Impact, Surveillance, and Governance*, 2022 SPACE: SCI. & TECH. 5–6 (2022) (discussing ground-based optical and radar observation systems for space surveillance); *Phased-Array Radars*, LEOLABS, https://leolabs.space/radars/ [https://perma.cc/MH7D-YVGA] (archived Sept. 18, 2023) (describing private sector ground-based facilities and equipment to monitor growing activity in space).

growing satellite population in an orderly fashion. Astronomy will provide an essential enabling technology for any such system.[11]

In addition, astronomy has played a vital contributing role in orbital developments that have gained widespread commercial and public use across the civilian economy, including Global Positioning System (GPS) navigation services and technologies for tracking the effects of climate change.[12]

Finally, in the realm of national security, the tools and techniques of astronomy contribute to the critical "early warning" function by detecting and tracking enemy missile tests and operational launches, speedily and reliably differentiating those from other seemingly-similar phenomena, and guiding interceptor anti-missiles to defeat them.[13] As potentially hostile activity in space continues to grow—with leading states accusing each other of rapidly militarizing the domain—astronomers' skills will provide crucial support for monitoring and assessing potential opponents' orbital behavior.[14]

---

11. Marlon E. Sorge, William H. Ailor & Ted J. Muelhaupt, *Space Traffic Management: The Challenge of Large Constellations, Orbital Debris, and the Rapid Changes in Space Operations*, CTR. FOR SPACE POL'Y AND STRATEGY 1–4 (2020), https://aerospace.org/sites/default/files/2020-09/Sorge_STM_20200915.pdf [https://perma.cc/3E7F-X3AU] (archived Sept. 18, 2023); Mir Sadat & Julia Siegel, *Space Traffic Management: Time for Action*, ATL. COUNCIL (Aug. 2, 2022), https://www.atlanticcouncil.org/in-depth-research-reports/issue-brief/space-traffic-management-time-for-action/ [https://perma.cc/MVB8-8PJE] (archived Sept. 18, 2023); *Space Policy Directive 3, National Space Traffic Management Policy*, THE WHITE HOUSE (June 18, 2018), https://trumpwhitehouse.archives.gov/presidential-actions/space-policy-directive-3-national-space-traffic-management-policy/ [https://perma.cc/X8GS-44VP] (archived Sept. 12, 2023); Paul B. Larsen, *Profit or Safety: Where Is Outer Space Headed?* 86 J. AIR LAW & COMMERCE 573–83 (2021) [hereinafter Profit or Safety; Theresa Hitchens, *SPACECOM, Commerce Wrapping Up Framework Accord on Space Surveillance*, BREAKING DEF. (June 27, 2022), https://breakingdefense.com/2022/06/spacecom-commerce-wrapping-up-framework-accord-on-space-surveillance/ [https://perma.cc/X5E9-2BJY] (archived Sept. 18, 2023) (describing Department of Commerce plans to move toward a space traffic management capability); LYALL & LARSEN, *supra* note 9, at 268–70 (discussing desirability of a space traffic management system).

12. 2020 Workshop, *supra* note 3, at 161–62; *see* HANDBOOK, *supra* note 6, at 4–8.

13. Theresa Hitchens, *SPACECOM Integrating Army, Navy Sensors to Improve Space Monitoring*, BREAKING DEF. (Aug. 9, 2022), https://breakingdefense.com/2022/08/spacecom-integrating-army-navy-sensors-to-improve-space-monitoring/ [https://perma.cc/AAK3-LDN7] (archived Sept. 18, 2023); HANDBOOK, *supra* note 6, at 8 (noting that active radar astronomy is most useful at relatively short ranges and provides the best mechanism for detecting and tracking debris and near-Earth natural objects).

14. Sandra Erwin, *U.S. Space Force Sees Future Demand for Surveillance Beyond Earth Orbit*, SPACENEWS (May 16, 2022), https://spacenews.com/u-s-space-force-sees-future-demand-for-surveillance-beyond-earth-orbit/ [https://perma.cc/KS7L-HD9H] (archived Sept. 18, 2023) (reporting increased military interest in using a variety of astronomy technologies to monitor other countries' activities further away in space); *see generally* Sandra Erwin, *Space Awareness: A Secret Weapon against Shadowy Threats in Orbit*, SPACENEWS (Apr. 14, 2022) (discussing military interest in monitoring other countries' military activities in space).

In sum, astronomy is not just some expensive, elite hobby for science nerds; it is an essential human cultural and scientific activity, it is vital to modern life, and it provides the essential pathway for ongoing and future exploration of the universe.[15]

B. *Facilities and Technologies*

There are several categories of astronomy, differentiated by the contrasting segments of the electromagnetic spectrum they seek to exploit; each provides its own insights and each requires its own specialized equipment and techniques.[16] For purposes of this Article, the primary focus is on optical astronomy (accessing visible light) and radio astronomy (studying electromagnetic radiation with wavelengths longer than about one millimeter, which is outside human visual range),[17] which are the two most common and most effective types for

---

15. Rosenberg, Russo, Bladon & Christensen, *supra* note 3, at 31 (quoting astronomers and philosophers about the tangible and intangible value of astronomy). Also note the avid global interest in astronomy as a hobby, engaging a wide community; it is unusual for amateurs to play a major role in advancing the cusp of hard science, but amateur astronomers have made major contributions. 2021 Workshop, *supra* note 2, at 21 (describing contributions by large numbers of amateur astronomers); Jessy Kate Schingler, Victoria Samson & Nivedita Raju, *Don't Delay Getting Serious About Cislunar Security,* WAR ON THE ROCKS (July 6, 2022), https://warontherocks.com/2022/07/dont-delay-getting-serious-about-cislunar-security/ [https://perma.cc/EZT7-KHPB] (archived Sept. 18, 2023) (emphasizing the role of "a small band of amateur trackers using equipment in their backyards" in detecting Chinese space maneuvers of national security importance); *Asteroid Collision Shows How Much Amateur Astronomers Have to Offer*, 615 NATURE 374, 374 (2023); *The Megaconstellation Threat*, FED'N OF ASTRONOMICAL SOC'YS., 1, 16–17 (2020).

16. *See generally* HANDBOOK, *supra* note 6, at 1 (noting that radio astronomy provides unique data, different from and complementary to what can be gleaned from optical telescopes). *See also* JASON*, supra* note 10, at 43 (addressing the effects of large satellite constellations on infrared astronomy); *id.* at 71–75 (microwave astronomy); *see* Elizabeth Howell, *Fermi Telescope: Studying the High-Energy Cosmos*, SPACE.COM (July 16, 2018), https://www.space.com/41191-fermi-gamma-ray-telescope.html [https://perma.cc/GH32-9LHB] (archived Sept. 19, 2023) (discussing gamma ray telescopes); *see NuSTAR - Mission Overview,* NASA (Aug. 3, 2017), https://www.nasa.gov/mission_pages/nustar/overview/index.html [https://perma.cc/S6X7-2MFZ] (archived Sept. 13, 2023) (discussing x-ray astronomy); *see Observatories Across the Electromagnetic Spectrum*, NASA (Feb. 2013), https://imagine.gsfc.nasa.gov/science/toolbox/emspectrum_observatories1.html [https://perma.cc/5JD2-FJHJ] (archived Sept. 13, 2023); *see also* Davide Castelvecchi, *Gravitational-Wave Detector LIGO Is Back – And Can Now Spot More Colliding Black Holes Than Ever*, NATURE (May 24, 2023), https://www.nature.com/articles/d41586-023-01732-4 [https://perma.cc/9PDY-ZLFB] (archived Sept. 19, 2023) (discussing gravitational wave observatories, which detect energy other than electromagnetic).

17. *See generally* 2020 Workshop, *supra* note 3, at 67–89 (regarding optical astronomy), 160–83 (regarding radio astronomy); HANDBOOK, *supra* note 6. Many optical observatories also access near-infrared and thermal infrared wavelengths, which can

ground-based observatories. An optical telescope is the more familiar technology, employed by observatories around the world to access light emitted by stars or reflected by other bodies.[18] A radio telescope collects and analyzes extremely faint cosmic radio waves, billions or trillions of times weaker than the standard signals of human radiocommunications.[19]

The output of an optical telescope is typically a collection of digital images or photographs on which illuminated pixels, as faint spots of light, represent stars or light-reflective objects such as planets or asteroids.[20] By comparing a time series of images from the same celestial position, astronomers can detect minute variations, indicative of relative movement of the bodies, and possibly leading to discovery of new objects or phenomena or to refined appreciation of their composition and behavior.[21] If a closer, brighter object (such as an Earth-orbiting satellite) intervenes, it will imprint a white spot, streak,

---

present different types of opportunities and problems. Olivier R. Hainaut & Andrew P. Williams, *Impact of Satellite Constellations on Astronomical Observations with ESO Telescopes in the Visible and Infrared Domains*, ASTRONOMY & ASTROPHYSICS 1, 1 (2020).

18. 2020 Workshop, *supra* note 3, at 70; *see* W.M. KECK OBSERVATORY, https://www.keckobservatory.org/ [https://perma.cc/N3ZB-WZ6M] (archived Sept. 13, 2023).

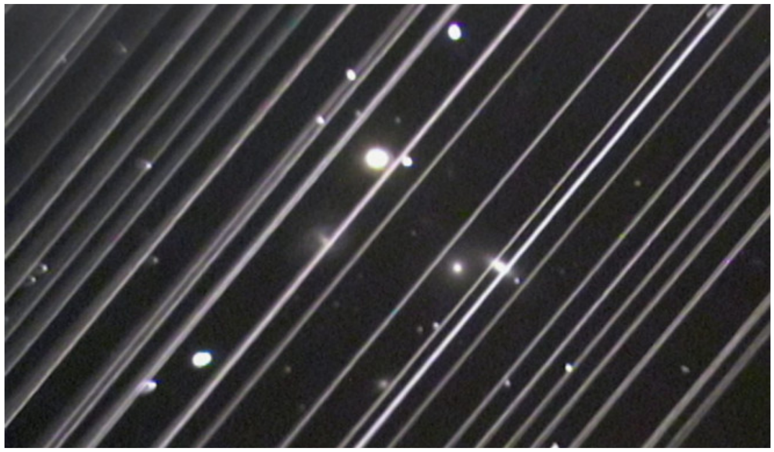
19. HANDBOOK, *supra* note 6, at 8; Andy Lawrence, Meredith L. Rawls, Moriba Jah, Aaron Boley, Federico Di Vruno, Simon Garrington, Michael Kramer, Samantha Lawler, James Lowenthal, Jonathan McDowell & Mark McCaughrean, *The Case for Space Environmentalism*, 6 NATURE 428, 431 (2022); 2020 Workshop, *supra* note 3, at 36–37, 147, 160–83; Mike Peel, Presentation at the Dark and Quiet Skies for Science and Society Conference: The Impact of Satellite Constellations on Cosmic Microwave Background Experiments (Oct. 7, 2021); 2020 Workshop, *supra* note 3, at 35 (noting discoveries attributed to radio astronomy, and concluding that "there are no other sources of such knowledge"). Note the difference between radar astronomy and radio astronomy: both employ radio waves, but the former is an "active" system, emitting signals and receiving the reflections from a target, while the latter is "passive," in only receiving signals from an extraterrestrial source.

20. HANDBOOK, *supra* note 6, at 8; Lawrence, Rawls, Jah, Boley, Vruno, Garrington, Kramer, Lawler, Lowenthal, McDowell & McCaughrean, *supra* note 19, at 431.

21. HANDBOOK, *supra* note 6, at 8; Lawrence, Rawls, Jah, Boley, Vruno, Garrington, Kramer, Lawler, Lowenthal, McDowell & McCaughrean, *supra* note 19, at 431.

or trail on the imagery, distorting, obliterating, or obscuring any view of the intended target.[22]

Visual #1



(Photo Credit: Victoria Girgis/Lowell Observatory)

Modern radio observations require the construction of distinctive, large metallic antennas and powerful receivers, passively collecting faint signals over a long stretch of time. The observatories—numbering some 130 around the world—have legally protected priority over other radio users for some selected frequencies, but must share (or compete in) most frequencies; the problem of interference looms large. The world's financial investment in radio astronomy is substantial: some installations carry price tags in the range of $400-$750 million, the new radio telescope in northern Chile cost $1.3 billion, and the forthcoming Square Kilometer Array is projected at $2.2 billion.[23] The product of a radio telescope can be a spectrum graph depicting the intensity of

---

22. *See, e.g.*, Visual #1.

23. 2020 Workshop, *supra* note 3, at 160–65; *Telescopes Curently Operating or Under Construction*, NAT'L SCI. FOUND., https://noirlab.edu/public/programs/telescopes/ [https://perma.cc/LY5F-HMGZ] (archived Sept. 13, 2023) (describing facilities and observatories); Jamie Carter, *Say Hello to the $2.2 Billion 'SKA' as Humanity's Biggest-Ever Telescope Gets the Green Light*, FORBES (July 2, 2021), https://www.forbes.com/sites/jamiecartereurope/2021/07/02/say-hello-to-the-22-billion-ska-as-humanitys-biggest-ever-telescope-gets-the-green-light/?sh=8417e82415de [https://perma.cc/F92A-YGZQ] (archived Sept. 19, 2023); SKAO, https://www.skao.int/en/partners [https://perma.cc/7Z9R-8GR5] (archived Sept. 13, 2023) (highlighting the number of nations belonging to SKAO); *see also* Robert Lea, *Major Radio Telescope 'Levels Up' to Get Unprecedented Views of the Early Universe*, SPACE.COM https://www.space.com/noema-radio-telescope-unprecedented-observations [https://perma.cc/83ZR-DDZ6] (archived Nov. 15, 2023) (Oct. 25, 2022) (reporting that the Northern Extended Millimeter Array, a powerful new radio telescope consisting of twelve networked antennas in the French Alps, has recently come fully on line).

various frequencies received, or it can be rendered in the form of an image, where interference again causes overexposure, leaving a white or blank pixel, occluding or distorting whatever might lie behind it, and conveying no usable information.[24]

Each type of telescope demands special conditions and care for optimal performance, and many different types of astronomical facilities are scattered around the world, in search of favorable situations. For optical telescopes, the goal is access to a dark night sky and clear air, such as may be found on an isolated island or a mountain (above much of the turbulent atmosphere and far removed from the light pollution of a city), especially in a region characterized by few clouds and low humidity.[25] Prime locations include Mauna Kea in Hawaii, Las Palmas in the Canary Islands, and northern Chile.[26]

For radio astronomy, darkness does not matter; the *sine qua non* is a quiet home, a location protected from the radio noise and microwave emissions that characterize so much of modern life and that

---

24. HANDBOOK, *supra* note 6; 2021 CRP, *supra* note 6, at 16; Lawrence, Rawls, Jah, Boley, Vruno, Garrington, Kramer, Lawler, Lowenthal, McDowell & McCaughrean, *supra* note 19, at 431 (describing the adverse effects of radio interference as not being a localized streak on an image, but "a complex effect across the whole map, which can be hard to recognize and remove – it is like trying to listen to very quiet music in a noisy room"); Technology Assessment, *supra* note 10, at 32–36.

25. 2020 Workshop, *supra* note 3, at 192 (describing the history of the search for dark, remote locations for optical telescopes). Note that this Article does not address the important, related problem of ground-based Artificial Light At Night (ALAN), which obscures observatories' visual access to the sky. ALAN also disrupts human and animal biorhythms, traditional and indigenous lifestyles that rely on natural darkness, and the pure enjoyment of viewing a pristine night sky. *See* 2020 Workshop, *supra* note 3, at 41–42, at 208–09 (summarizing effects of excessive light on flora and fauna); 2021 Workshop, *supra* note 3, at 17 (noting that global light pollution is growing at an estimated rate of 2–6% per year); Christopher C. M. Kyba, Yigit Oner Altintas, Constance E. Walker & Mark Newhouse, *Citizen Scientists Report Global Rapid Reductions in the Visibility of Stars from 2011 to 2022*, 379 SCI. 265, 267 (2023) (summarizing observations reporting a 9.6% annual increase in global light pollution); *see generally* Phil Plait, *Worsening Light Pollution*, SCI. AM. (Jan. 31 2023), https://www.scientificamerican.com/article/light-pollution-is-dimming-our-view-of-the-sky-and-its-getting-worse/ [https://perma.cc/PJE3-LB2X] (archived Sept. 26, 2023); *see* 2021 CRP, *supra* note 6, at 7–15; *see generally Report on the United Nations/Spain/International Astronomical Union Conference on Dark and Quiet Skies for Science and Society*, ¶¶ 20–22, U.N. Doc. A/AC.105/1255 (Nov. 5, 2021) [hereinafter 2021 Report]; Kevin J. Gaston, Sian Gaston, Jonathan Bennie & John Hopkins, *Benefits and Costs of Artificial Nighttime Lighting of the Environment*, 23 ENV'TAL REV. 14, 14–18 (2014) (summarizing many benefits and costs of lighting, including impacts on human health, highway safety, and crime); *see generally* Fabio Falchi, Salvador Bara, Pierantonio Cinzano, Raul C. Lima & Martin Pawley, *A Call for Scientists to Halt the Spoiling of the Night Sky with Artificial Light and Satellites*, 7 NATURE ASTRONOMY 237, 237 (2023); *see* Joshua Sokol, *The Sky Needs Its 'Silent Spring' Moment*, SCI. AM. (Oct. 1, 2022), https://www.scientificamerican.com/article/the-sky-needs-its-silent-spring-moment/ [https://perma.cc/4Q9T-NJEM] (archived Sept. 20, 2023); Duane Hamacher, Krystal De Napoli & Bon Mott, *Whitening the Sky: Light Pollution as a Form of Cultural Genocide*, 1 J. DARK SKY STUDS. 1, 2 (2020).

26. 2020 Workshop, *supra* note 3, at 67 (noting forty large observatories in the United States, Chile, Spain, South Africa, Russia, China, Australia, and India.

overwhelm and drown out faint celestial signals. One prominent such facility is at Green Bank, West Virginia, nestled in an isolated Appalachian zone, protected from competing terrestrial transmissions.[27] Another is the Square Kilometer Array, a collaboration among fifteen countries with a networked array of radio telescopes being constructed in Australia and South Africa.[28]

In the urbanized twenty-first century, few locales can reliably ensure access to a dark and/or quiet sky, but astronomers have adapted as best they can within natural and financial constraints. There are 350 active professional observatories in the United States and 600 more around the world, many supported by consortia of governments, universities, and foundations, and often sited in obscure mountaintop, desert, or island locales.[29]

In addition to the ground-based observatories, there are important telescopes in space, with NASA's Hubble and Webb telescopes

---

27. GREEN BANK OBSERVATORY, 2022 GREEN BANK OBSERVATORY 1 (2022); https://greenbankobservatory.org/wp-content/uploads/2021/12/2022-Green-Bank-Observatory-Booklet-PDF.pdf [https://perma.cc/XX4H-323U] (archived Nov. 15, 2023); *see also* Nat'l Acads. of Scis., Eng'g, & Med., Presentation on Pathways to Discovery in Astronomy and Astrophysics for the 2020s (Nov. 4, 2021) [hereinafter Nat'l Acads.] (recommending the start of work on a $3.2 billion Next Generation Very Large Array radio observatory in Arizona); Jeff Foust, *Astrophysics Decadal Survey Recommends a Program of Flagship Space Telescopes*, SPACENEWS (Nov. 4, 2021), https://spacenews.com/astrophysics-decadal-survey-recommends-a-program-of-flagship-space-telescopes/ [https://perma.cc/76MQ-MPBN] (archived Sept. 21, 2023); *see U.S. Radio Astronomy Telescopes*, GO ASTRONOMY, https://go-astronomy.com/radio-telescopes.php [https://perma.cc/MJZ6-AUF4] (archived Sept. 13, 2023) (listing radio observatories in the United States and worldwide).

28. *See The construction journey*, SKAO, https://www.skao.int/en/explore/construction-journey [https://perma.cc/K2VY-268P] (archived Sept. 22, 2023); Tereza Pultarova, *World's Largest Radio Telescope to Be Built After Almost 30 Years of Planning*, SPACE.COM (June 30, 2021), https://www.space.com/square-kilometer-array-telescope-construction-starts [https://perma.cc/GU9C-L4FV] (archived Sept. 22, 2023); Cassandra Cavallaro, *SKAO Needs Corrective Measures from Satellite 'Mega-Constellation' Operators to Minimise Impact on Its Telescopes*, SKAO (Oct. 7, 2020), https://www.skao.int/en/news/198/skao-needs-corrective-measures-satellite-mega-constellation-operators-minimise-impact-its#:~:text=SKAO%20would%20require%20operators%20to,constellation's%20deployment%2C%20positioning%20or%20hardware [https://perma.cc/T8U3-M7LU] (archived Sept. 22, 2023).

29. *Observatories*, GO ASTRONOMY, https://www.go-astronomy.com/observatories.html [https://perma.cc/W89Y-QTCP] (archived Sept. 13, 2023); 2021 Workshop, *supra* note 2, at 20 (describing the three largest telescopes planned for construction this decade as combining the efforts of five to seventeen countries), 224 (noting 300 observatories in the United States); 2020 Workshop, *supra* note 3, at 67, 70; 2021 CRP, *supra* note 6, at 3 (observing that "[m]odern astronomical optical observatories represent large public investments," which "governments have an interest in protecting"); *Observatory Sites*, VIK DHILLON, http://www.vikdhillon.staff.shef.ac.uk/teaching/phy217/telescopes/phy217_tel_sites.html [https://perma.cc/LA8Q-7ASY] (archived Sept. 13, 2023) (discussing factors that influence the optimal location for an observatory).

providing the leading contemporary optical exemplars. Space-based radio telescopes have also proven invaluable over the past twenty-five years, and other orbiting observatories are proliferating. Depending on their altitude in space, these facilities can escape much (but not all) terrestrial and orbital noise and light, but they carry an intimidating price tag: $1.5 billion for Hubble and $10 billion for Webb.[30] By one

30. The Hubble Space Telescope orbits at 540 kilometers altitude, approximately the same as the Starlink constellation, but much lower than OneWeb satellites. *See* 2020 Workshop, *supra* note 3, at 149 (noting that 5% of the imagery obtained by the Hubble Space Telescope is affected by trails of light reflected by satellites); 2021 CRP, *supra* note 6, at 5 (noting that the interference from LEO satellites affects space-based telescopes too, "and in those cases, mitigations are more challenging to implement"); Letter from Kathy Smith, Chief Counsel, Nat'l Telecomms. & Info. Admin., to Marlene Dortsch, Secretary, Fed. Commc'ns. Comm'n (Feb. 9, 2022) [hereinafter NASA FCC Letter] (on file with U.S. Dep't of Commerce) (reporting that 8% of Hubble's images are impacted by satellites, and that ratio could double with Starlink's expansion); Technology Assessment, *supra* note 10, at 28; Lawrence, Rawls, Jah, Boley, Vruno, Garrington, Kramer, Lawler, Lowenthal, McDowell & McCaughrean, *supra* note 19, at 432 (estimating that by 2030, one-third of Hubble's images will be affected by satellite interference); *Astronomers Are Reducing Satellite Interference in Hubble Images*, SPACE TELESCOPE SCI. INST. (June 5, 2023), https://www.stsci.edu/contents/news-releases/2023/news-2023-017 [https://perma.cc/Q3V8-9DMY] (archived Sept. 23, 2023) (reporting that satellites interfere with 10% of Hubble's images, but since each streak leaves only a very narrow line on an image, less than 0.5% of Hubble's work is affected, and the satellite trails have not had a significant impact on the observatory's research; refined techniques for cleaning up the satellite artifacts can further reduce their effects); Michael M. Shara & Mark D. Johnston, *Artificial Earth Satellites Crossing the Fields of View of, and Colliding with, Orbiting Space Telescopes*, 98 PUBL'NS ASTRONOMICAL SOC'Y PAC. 814, 814 (1986) (anticipating effects of satellite interference with Hubble and other space telescopes); Order Dismissing Motion for Abeyance of DISH Network Corporation, FCC 22-91, 47 (2022) [hereinafter FCC 2022 Order]; 2021 Report, *supra* note 25, at ¶ 34 (reporting that "satellites were already affecting space-based astronomical observations")*; see also* HANDBOOK, *supra* note 6, at 33–34 (discussing space-based radio astronomy). The 2020 Decadal Survey prepared by a National Academy of Sciences committee has recommended a vigorous, multi-billion-dollar program of new space-based telescopes, including some that would access distinct parts of the electromagnetic spectrum. Nat'l Acads., *supra* note 27; Foust, *supra* note 27; Dennis Overbye, *A New 10-Year Plan for the Cosmos*, N.Y. TIMES (Nov. 4, 2021), https://www.nytimes.com/2021/11/04/science/astronomy-decadal-survey-telescope.html [https://perma.cc/KWC4-CAWJ] (archived Sept. 23, 2023); Igor Levchenko, Shuyan Xu, Yue-Liang Wu, & Kateryna Bazaka, *Hopes and Concerns for Astronomy of Satellite Constellations*, 4 NATURE ASTRONOMY 1012, 1012 (2020); *see also* Am. Astronautical Soc'y & Inst. of Physics Publ'g, *supra* note 8 (describing role of NEOWise and NEOSSat space-based telescopes in planetary defense); Leonid I. Gurvits, *Space VLBI: From First Ideas to Operational Missions*, ADVANCES IN SPACE RSCH. (2019) (describing the historical evolution of space-based radio astronomy); *New Era of 'Great Observatories' May Be Coming for NASA*, NEWS SOC. (Nov. 8, 2021), https://en.news4social.com/space/new-era-of-great-observatories-may-perhaps-be-coming-for-nasa/ [https://perma.cc/HKJ2-GVXT] (archived Sept. 23, 2023) (describing four recent giant space telescopes); *List of Space Telescopes*, WIKIPEDIA, https://en.wikipedia.org/wiki/List_of_space_telescopes [https://perma.cc/U63D-4BTW] (archived Sept. 13, 2023) (collecting roster of space telescopes that access different parts of the electromagnetic spectrum and other phenomena); Evgenya L. Shkoknik, *On the Verge of an Astronomy CubeSat Revolution*, 2 NATURE ASTRONOMY 1, 374 (2018) (describing small space-based astronomy vehicles).

estimate, ground-based optical telescopes can generally be two orders of magnitude less expensive than those launched into orbit.[31]

In sum, astronomy provides enormous service to humanity but faces equally daunting challenges, both in financial terms and in the difficulty of securing and sustaining suitable locales and conditions for the facilities, while avoiding the encroachments of damaging interference and contamination. Some private actors and some governments may be able to afford to navigate these constraints, while others, whose contributions may be no less profound, are in danger of being squeezed out of an ancient profession by the noise and light pollution of modern life.

III. SATELLITES

Satellites serve an immense and ever-expanding array of invaluable functions for people and countries around the world. Three broad categories of applications may be usefully discerned. First, among the oldest and most important purposes—and still accounting for a large share of space activity today—are military and intelligence community operations. These include communications (establishing secure, effective, resilient lines of command and coordination, both intra-theater and globally); reconnaissance (locating enemy forces, discerning their characteristics, and differentiating them from civilians); warning (detecting adversary missile launches and guiding interceptors); and monitoring (verifying compliance with arms control agreements). The United States is the world's leading practitioner of national security space, with an estimated 237 dedicated satellites fulfilling those roles; other states are avidly pursuing similar capabilities.[32]

---

31. 2020 Workshop, *supra* note 3, at 19 (also noting that ground-based facilities are "often essential to interpret observations from space-based telescopes"); *see also* Comm. on the Peaceful Uses of Outer Space, Rep. of the Scientific and Technical Subcomm. on Its Fifty-Ninth Session, ¶¶ 1–2, U.N. Doc. A/AC.105/C.1/L.396 (2021) [hereinafter 2021 Working Paper] (noting the contributions of "tens" of scientific astronomy satellites, providing "irreplaceable" data about space, but concluding that space astronomy alone would be insufficient without "the essential complementary contribution of large ground astronomical facilities"); Williams, *supra* note 3 (discussing synergies between ground-based and space-based observatories); *Ask Ethan: Do We Still Need Ground-Based Astronomy?*, BIG THINK (Feb. 4, 2022), https://bigthink.com/starts-with-a-bang/ground-based-astronomy/ [https://perma.cc/G56M-JLP3] (archived Sept. 13, 2023).

32. *See UCS Satellite Database*, UNION OF CONCERNED SCIENTISTS (Dec. 8, 2005), https://www.ucsusa.org/resources/satellite-database?_gl=1*ctiw2q*_ga*MTI4NTk4NDA0NC4xNjYyMDUyMTY1*_ga_VB9DKE4V36*MTY2MjA1MjE2NS4xLjEuMTY2MjA1MjE4My4wLjAuMA [https://perma.cc/BSH5-5H4E] (archived Sept. 13, 2023); Stephen Bryen, *Musk's Tech Put to Deadly Weapon Effect in Ukraine*, ASIA TIMES (July 1, 2022),

The second category is civil space, embracing planet-wide shared utilities, such as GPS for positioning, navigation, and timing, and its emerging counterparts launched by China, Russia, and the European Union/European Space Agency. Satellites employed for weather forecasting, mapping, space exploration, search-and-rescue missions, and detection of potentially hazardous asteroids and comets also fit this category, as does the International Space Station.[33] ·

Finally, and of escalating significance, is the third sphere, private and commercial space, where recent radical reductions in the cost of creating and launching satellites have spawned a prodigious growth in activity. Numerous startup companies in the United States and elsewhere have flocked to these newfound opportunities, offering cut-price competition for communications, Earth sensing, and other services.[34]

Notably, this "New Space" revolution features the establishment of large constellations of small, inexpensive satellites in Low Earth Orbit (LEO)—less than 2000 kilometers above the surface of the

---

https://asiatimes.com/2022/07/musks-tech-put-to-deadly-weapon-effect-in-ukraine/ [https://perma.cc/W345-FE9H] (archived Sept. 23, 2023) (highlighting use of the Starlink satellite communications system in assisting Ukraine's military by linking information from reconnaissance drones to artillery and rocket forces); *How Elon Musk's Satellites Have Saved Ukraine and Changed Warfare*, ECONOMIST (Jan. 5, 2023), https://www.economist.com/briefing/2023/01/05/how-elon-musks-satellites-have-saved-ukraine-and-changed-warfare [https://perma.cc/Q92J-MB9S] (archived Sept. 23, 2023).

33. LYALL & LARSEN, *supra* note 9, at 340–58 (discussing Global Navigation Satellite Systems, including GPS and its international competitors); *see generally* Paul B. Larsen, *Will Harmful Interference Bring GPS Down?* 86 J. AIR L. & COMMERCE 2 (2021) (discussing U.S. and other Global Navigation Satellite Systems); J.R. Elliot, R.J. Walters & T.J. Wright, *The Role of Space-Based Observation in Understanding and Responding to Active Tectonics and Earthquakes*, 7 NATURE COMMUNICATIONS 1 (Dec. 22, 2016), https://www.nature.com/articles/ncomms13844.pdf [https://perma.cc/3MN3-727E] (archived Sept. 26, 2023) (discussing role of Earth-monitoring satellites in detecting potential for earthquakes and studying their effects by irradiating microwaves from space to Earth); *United Nations Platform for Space-Based Information for Disaster Management and Emergency Response (UN-SPIDER)*, U.N. OFF. OUTER SPACE AFFS., https://www.unoosa.org/oosa/en/ourwork/un-spider/index.html [https://perma.cc/P7AH-FTNC] (archived Sept. 13, 2023) (discussing use of space assets to assist in disaster management); U.S. DEP'T OF STATE, A STRATEGIC FRAMEWORK FOR SPACE DIPLOMACY (2023) (surveying benefits of space operations).

34. JASON, *supra* note 10, at 11 (noting sharp reductions in costs of satellite launches and operations); Bryen, *supra* note 32 (emphasizing that previous generations of communications satellites were not capable of nearly the speed and quality of service that can be achieved today); Aparna Venkatesan, James Lowenthal, Parvathy Prem & Monica Vidaurri, *The Impact of Satellite Constellations on Space as an Ancestral Global Commons*, 4 NATURE ASTRONOMY 1043, 1044 (2020) (emphasizing the social value of democratizing the access to space, providing widely-available low-cost communications services for dispersed communities); *The Megaconstellation Threat*, *supra* note 15, at 10 (emphasizing the dramatic recent reduction in the cost of placing a satellite into orbit); MICHAEL BYERS & AARON BOLEY, WHO OWNS OUTER SPACE? 48–52 (Larissa van den Herik & Jean d'Aspremont eds., 2023).

planet.[35] In contrast to the legacy systems, which relied on smaller numbers of large, exquisite, expensive, multi-purpose, high-altitude spacecraft, the new configuration promises a nimble, diversified structure, capable of adapting swiftly to new technologies, markets, and other conditions.[36]

The bellwether for the private sector in this new enterprise is SpaceX, a US corporation led by Elon Musk, which (in addition to other high-profile space activities) is developing the Starlink satellite constellation to provide commercial internet services on a global scale. With initial launches in 2019, Starlink is already the largest satellite network ever established; as of July 9, 2023, it comprises 4,375 operational spacecraft in orbit and provides service to 1.5 million customers.[37] SpaceX has plans (and regulatory authorization) to

---

35. Generally, low Earth orbit (LEO) is defined as altitudes less than 2,000 kilometers above the surface; medium Earth orbit (MEO) is 2,000 to 35,000 kilometers (with special interest at around 20,000 kilometers); and geosynchronous orbit (GEO) is 35,800 kilometers. Lawrence, Rawls, Jah, Boley, Vruno, Garrington, Kramer, Lawler, Lowenthal, McDowell & McCaughrean, *supra* note 19, at 429; MELISSA DE ZWART & JOEL LISK, LOW EARTH ORBIT, SATELLITE CONSTELLATIONS AND REGULATION 11–12 (Flinders Univ. ed., 2022); *The Megaconstellation Threat*, *supra* note 15, at 4. A constellation or megaconstellation can be defined as a group of associated satellites functioning together in order to fulfill a common objective, involving simultaneous coverage of large swaths of the Earth for different types of functions. Soumyaa Rawat, *What Is a Satellite Mega-Constellation? Advantages and Disadvantages*, ANALYTIC STEPS (May 8, 2021), https://www.analyticssteps.com/blogs/what-satellite-mega-constellation-advantages-and-disadvantages [https://perma.cc/E22P-PZVS] (archived Sept. 23, 2023). By one standard measure, a constellation of over one hundred linked satellites is deemed "large." ORBITAL DEBRIS MITIGATION STANDARD PRACTICES § 5 (U.S. Gov't 2019); CONG. BUDGET OFF., LARGE CONSTELLATIONS OF LOW-ALTITUDE SATELLITES: A PRIMER __ (2023) [hereinafter CBO].

36. *See* Omkar Nikam, *Opportunities Emerging from "New Space,"* SATELLITE MKTS. & RSCH., http://satellitemarkets.com/news-analysis/opportunities-emerging-new-space [https://perma.cc/7V7K-ZHZQ] (archived Sept. 13, 2023); *NewSpace*, SPACETEC PARTNERS, https://www.spacetec.partners/markets/newspace/#:~:text=NewSpace%20refers%20to%20the%20emergence,traditional%20space%20industry%20supply%20chain [https://perma.cc/WLF4-3ZTM] (archived Sept. 13, 2023); *Low Earth Orbit: Disruptive Military Technologies*, TS2 SPACE, https://ts2.shop/en/posts/low-earth-orbit-disruptive-military-technologies-airforce-technology [https://perma.cc/5LN2-ESKM] (archived Sept. 24, 2023) (highlighting the advantages of LEO satellites for communications and other vital military services); Christopher D. Johnson, *The Legal Status of MegaLEO Constellations and Concerns about Appropriation of Large Swaths of Earth Orbit*, *in* HANDBOOK OF SMALL SATELLITES: TECHNOLOGY, DESIGN, MANUFACTURE, APPLICATIONS, ECONOMICS AND REGULATION 1337, 1338–39 (Joseph N. Pelton & Scott Madry eds., 2020) (describing unique characteristics of new space operations); LYALL & LARSEN, *supra* note 9, at 239–44 (discussing the legal implications of large constellations of small satellites); CBO, *supra* note 35.

37. *See* Jonathan McDowell, *Starlink Statistics*, JONATHAN'S LEGACY, https://planet4589.org/space/con/star/stats.html [https://perma.cc/L5AQ-U54Z] (archived Sept. 13, 2023) (as of July 9, 2023, there had been 4,746 Starlink satellites launched, 4,411 were still in orbit, and 4,375 were operational); *UCS Satellite Database*,

deploy a total fleet of up to 40,000 satellites in the coming years and is proceeding to implement a larger, more capable Starlink Generation 2 satellite design.[38] The currently underserved global market for ultra-low-latency internet service is immense and projected to swell further, with satellites providing the best new capability.[39] Enhanced service, especially to rural and remote areas, will help promote an integrated digital society, sustainable global development, ubiquitous tele-medicine and other remote services, and enhanced military capabilities.[40]

Other competitors seem equally ambitious. OneWeb, a British company, now (after emerging from a 2020 bankruptcy) partially owned by the UK government, originally aimed to deploy 47,844

UNION OF CONCERNED SCIENTISTS (Dec. 8, 2005), https://www.ucsusa.org/resources/satellite-database [https://perma.cc/V4YV-WLNZ] (archived Sept. 13, 2023); Michael Sheetz, *Investing in Space: Is SpaceX's Starlink Growing Satellite Internet Market Share, or Taking It?*, CNBC (May 18, 2023, 12:40 PM), https://www.cnbc.com/2023/05/18/investing-in-space-where-spacexs-starlink-is-growing-market-share.html [https://perma.cc/L2YP-GHLE] (archived Sept. 24, 2023) (reporting that Starlink has attracted 1.5 million subscribers).

38. *See SpaceX's Approach to Space Sustainability and Safety*, SPACEX (Feb. 22, 2022), https://www.spacex.com/updates/ [https://perma.cc/AX7V-PCRN] (archived Sept. 13, 2023); 2020 Workshop, *supra* note 3, at 216–17 (describing the Starlink Generation 2 satellite constellation of 30,000, based on SpaceX's May 2020 filings); FCC 2022 Order, *supra* note 30, at 47 (granting SpaceX authority to proceed with 7,500 Generation 2 satellites); JASON, *supra* note 10, at 13–15; BRIGHTNESS MITIGATION BEST PRACTICES FOR SATELLITE OPERATORS, SPACEX (July 30, 2022), https://api.starlink.com/public-files/BrightnessMitigationBestPracticesSatelliteOperators.pdf [https://perma.cc/6QGD-F4GF] (archived Nov. 15, 2023) (describing improved adaptations that SpaceX has instituted on second-generation Starlink satellites, to reduce their reflectivity effects on Earth); Brian Wang, *Version 2 Starlink with Lasers and Gen2 SpaceX Starlink Bigger and Faster*, NEXT BIG FUTURE (Sept. 27, 2021), https://www.nextbigfuture.com/2021/09/version-2-starlink-with-lasers-and-gen-2-spacex-starlink-bigger-and-faster.html [https://perma.cc/QBZ3-TKD7] (archived Sept. 24, 2023); *Second Generation Starlink Satellites*, SPACEX (Feb. 26, 2023), https://api.starlink.com/public-files/Gen2StarlinkSatellites.pdf [https://perma.cc/P5VX-K53S] (archived Sept. 13, 2023).

39. JASON, *supra* note 10, at 26 (reporting that "the overall Internet business is estimated to be $1T/year"); Amy Borrett, *Satellite Broadband is the Future of the $1trn Space Economy*, NEWS STATESMAN MEDIA GRP. (Mar. 31, 2023, 10:41 AM), https://techmonitor.ai/technology/cloud/satellite-broadband-future-1trn-space-economy [https://perma.cc/LHA8-YU42] (archived Sept. 24, 2023) (reporting that the race to provide low-cost, high-speed internet service is fueling the space economy, expected to reach $1 trillion globally by 2040); Nathan Strout, *Elon Musk Dismisses Astronomers' Concerns Over Starlink*, C4ISR (Mar. 9, 2020), https://www.c4isrnet.com/battlefield-tech/space/2020/03/09/elon-musk-dismisses-astronomers-concerns-over-starlink/ [https://perma.cc/NJ7U-EDKR] (archived Sept. 24, 2023) (projecting that Starlink's broadband services could earn $30 billion per year); MAKENA YOUNG & AKHIL THADANI, LOW ORBIT, HIGH STAKES: ALL-IN ON THE LEO BROADBAND COMPETITION 1 (CTR. FOR STRATEGIC AND INT'L STUD. ed., 2022) (projecting that the global market for satellite-based communications services will reach $40 billion by 2030).

40. 2021 Workshop, *supra* note 2, at 104; YOUNG & THADANI, *supra* note 39, at 3–4 (stressing the advantages of low-latency communications, via satellites operating at low altitudes); BYERS & BOLEY, *supra* note 34, at 48–52; Borrett, *supra* note 39 (observing that 20% of the world's population does not have access to modern communications, with much higher percentages underserved in Africa).

communications satellites in orbit.[41] More recently, it has scaled back to a constellation of 6,372; 632 are already in place.[42] Amazon has projected its own fleet of 3,236 Kuiper satellites.[43] Among other countries, the government of China is building toward an array of 12,992 communications satellites in its Guowang (or China SatNet) network, and Russia recently announced plans to launch 640 small satellites in its Sfera system.[44] Nor is this game confined to the

41. 2020 Workshop, *supra* note 3, at 217.

42. *See* Jonathan McDowell, *OneWeb Launch Statistics*, JONATHAN'S LEGACY, https://planet4589.org/space/con/ow/stats.html [https://perma.cc/4BQX-8ENX] (archived Sept. 24, 2023); *see* ONEWEB, https://oneweb.net/ [https://perma.cc/8MBC-D2LM] (archived Sept. 24, 2023); 2020 Workshop, *supra* note 3, at 217 (describing the OneWeb Phase 2 satellite constellation of 48,000 based on the company's May 2020 filings); Cat Hofacker, *How to Make a Megaconstellation*, AM. INST. AERONAUTICS & ASTRONAUTICS (March 2020), https://aerospaceamerica.aiaa.org/features/how-to-make-a-megaconstellation/ [https://perma.cc/M4KR-RH55] (archived Sept. 24, 2023) (describing OneWeb); CHRISTOPH BEISCHL, SATELLITE MEGA-CONSTELLATION SAFETY AND SECURITY 25–26 (London Inst. Space Pol'y & Law, ed., 2021).

43. Thomas Kohnstamm, *Everything You Need to Know about Project Kuiper, Amazon's Satellite Broadband Network*, AMAZON (Mar. 14, 2023), https://www.aboutamazon.com/news/innovation-at-amazon/what-is-amazon-project-kuiper#:~:text=10.-,How%20many%20satellites%20will%20Project%20Kuiper%20have%3F,constellation%20design%20includes%203%2C236%20satellites [https://perma.cc/B38R-8Y3J] (archived Sept. 24, 2023); *see* NEWSPACE INDEX, https://www.newspace.im/ [https://perma.cc/FN29-W3J5] (archived Sept. 24, 2023) (identifying dozens of planned satellite constellations); Zhang, Cai, Xue, Xue & Ca, *supra* note 10, at 3-4 (discussing several companies' planned fleets of LEO satellites); YOUNG & THADANI, *supra* note 39, at 6–7; Rafael Moro-Aguilar, *Megaconstellations of Satellites and Their Impact on Astronomy: A Potential Need for International Regulation*, 64 INT'L INST. SPACE LAW 489 (2021); Donny Jackson, *Lynk Announces Deployments, Plans for Spring Satellite-Direct-to-Phone Commercial Service,* INFORMA TECH (Jan. 14, 2023), https://urgentcomm.com/2023/01/14/lynk-announces-deployments-plans-for-spring-satellite-direct-to-phone-commercial-service/ [https://perma.cc/P9VE-4CN3] (archived Sept. 24, 2023) (reporting that Lynk hopes to deploy 1000 satellites by 2025, with an ultimate goal of 5000).

44. Andrew Jones, *China's Megaconstellation Project Establishes Satellite Cluster in Chongqing*, SPACENEWS (Jan. 12, 2020), https://spacenews.com/chinas-megaconstellation-project-establishes-satellite-cluster-in-chongqing/ [https://perma.cc/Y3UJ-GDBL] (archived Sept. 25, 2023); Brian Waidelich, *A Chinese Starlink? PRC Views on Building a Satellite Internet Megaconstellation*, 21 JAMESTOWN FOUND. 10, 10 (2021); Larry Press, *Guowang, Renamed China SatNet, Will Be China's Global Broadband Provider*, CircleID (Mar. 29, 2021), https://circleid.com/posts/20210329-guowang-starlink-will-be-chinas-global-broadband-provider/ [https://perma.cc/MWM8-HFAA] (archived Sept. 25, 2023); YOUNG & THADANI, *supra* note 39, at 10–13 (discussing Chinese plans for large communications satellite constellations); *Sfera Satellite System Gets Green Light*, SPACEWATCH.GLOBAL, https://spacewatch.global/2018/07/sfera-satellite-system-gets-green-light/, [https://perma.cc/R3M3-E6HA] (archived Sept. 25, 2023); *see also, e.g.*, JASON, *supra* note 10, at 16 (listing several large constellations of planned satellites, including significant fleets from Canada, Norway, Korea, India, Poland, France, Liechtenstein, Germany, and elsewhere); C.G. Bassa, O.R. Hainaut & D. Galadi-Enriquez, *Analytical Simulations of*

superpowers: Germany, Canada, and even Rwanda have filed for regulatory approval of megaconstellations, and analysts anticipate the possibility of 100,000 or more satellites in orbit within the coming decade or so.[45]

Aside from the focus on communications, there is also surging interest in establishing new fleets of small LEO-based remote sensing satellites. Use of space-based platforms for monitoring Earth activities is nothing new; governments have undertaken photoreconnaissance and other, more active, forms of observation such as synthetic aperture radar sensing, for decades, for military and civil purposes. What is new is the current proliferation of privately-owned sensing satellites, offering ubiquitous services in optical and other monitoring, for clients in agriculture, military intelligence, land use, emergency response, climate change detection, and more.[46] Planet Labs, for example, now

---

the Effect of Satellite Constellations on Optical and Near-Infrared Observations, 657 ASTRONOMY & ASTROPHYSICS 1, 2 (2022) (listing several planned or announced large LEO constellations); Donatas Palavenis, *The Growing Importance of Small Satellites in Modern Warfare: What Are the Options for Small Countries?*, SPACE REV. (Dec. 5, 2022), https://www.thespacereview.com/article/4492/1 [https://perma.cc/J9LA-DVEL] (archived Sept. 25, 2023) (discussing planned satellite constellations from many companies and countries); *Welcome IRIS2: EU's New Communication Satellite Infrastructure*, EUR. UNION AGENCY FOR THE SPACE PROGRAMME, https://latviaspace.gov.lv/en/news-events/welcome-iris-eus-new-communication-satellite-infrastructure/#:~:text=It%20may%20include%20the%20development,satellites%20between%202025%20and%202027 [https://perma.cc/HW93-E5VR] (archived Sept. 25, 2023) (discussing EU agreement to create a satellite constellation that could launch 170 LEO satellites between 2025 and 2027).

45. NEWSPACE INDEX, *supra* note 43; Lawrence, Rawls, Jah, Boley, Vruno, Garrington, Kramer, Lawler, Lowenthal, McDowell & McCaughrean, *supra* note 19, at 428 (reporting one filing with the ITU requesting authorization for 327,000 satellites); Rebecca Boyle, *Satellite Constellations Are an Existential Threat for Astronomy*, SCI. AM. (Nov. 7, 2022), https://www.scientificamerican.com/article/satellite-constellations-are-an-existential-threat-for-astronomy/ [https://perma.cc/9AXV-2NM2] (archived Sept. 25, 2023) (reporting that official filings indicate that 431,713 satellites in sixteen constellations are planned for launch) [hereinafter Boyle, 2023]; Jon Brodkin, *Firm Planning 100,000 Satellites Claims It Will "Clean Space" by Capturing Debris*, CONDE NAST. & ARS TECHNICA ADDENDUM (Feb. 8, 2022), https://arstechnica.com/information-technology/2022/02/firm-planning-100000-satellites-claims-it-will-clean-space-by-capturing-debris/ [https://perma.cc/83UM-YRQG] (archived Sept. 25, 2023) (reporting plans by E-Space to place 100,000 small communications satellites into orbit); *supra* note 8, at 6 (noting multiple sources anticipate 58,000 additional satellites in orbit by 2030); Jeff Foust, *Satellite Operators Criticize "Extreme" Mega-constellation Filings*, SPACENEWS (Dec. 14, 2021), https://spacenews.com/satellite-operators-criticize-extreme-megaconstellation-filings/ [https://perma.cc/T7XY-AVYE] (archived Sept. 25, 2023) (reporting Rwanda filing for 327,230 satellites and a private Canadian company filing for 115,000); *see generally* Chris Forrester, *Rivada Confirms Plans for LEO Constellation*, ADVANCED TELEVISION (Mar. 25, 2022), https://advanced-television.com/2022/03/25/rivada-confirms-plans-for-leo-constellation/ [https://perma.cc/N7NW-ZPAC] (archived Sept. 25, 2023).

46. *See* LYALL & LARSEN, *supra* note 9, at 359–86 (discussing remote sensing satellites and applicable international law); Todd Harrison & Matthew Strohmeyer, *Commercial Space Remote Sensing and Its Role in National Security*, CTR. FOR

STRATEGIC & INT'L STUD. (Feb. 2, 2022), https://www.csis.org/analysis/commercial-space-remote-sensing-and-its-role-national-security [https://perma.cc/S2Q2-5WNH] (archived Sept. 25, 2023) (describing search for extraterrestrial intelligence); JOHN M. OLSON, STEVEN J. BUTOW, ERIC FELT & THOMAS COOLEY, STATE OF THE SPACE INDUSTRIAL BASE 2022 84–85 (Peter Garrettson ed., 2022) (forecasting a seven-fold growth in commercial remote sensing in a decade); *Inaugural EO+ & Geospatial Quarterly Brief From Quilty Analytics*, SATNEWS (Jan. 12, 2022), https://news.satnews.com/2022/01/11/inaugural-eo-geospatial-quarterly-briefing-debuts-from-quilty-analytics/ (describing market factors driving an anticipated surge in space-based Earth sensing) [https://perma.cc/8N9R-NVUN] (archived Sept. 25, 2023); Catherine Amirfar, Ina Popova, Christel Tham & Nicole Marton, *Remote Sensing from Space: What Norms Govern?*, JUST SECURITY (May 5, 2023), https://www.justsecurity.org/86114/remote-sensing-from-space-what-norms-govern/ [https://perma.cc/L45E-6PR5] (archived Sept. 25, 2023) (underscoring the proliferation of remote sensing satellites, now totaling 1100 active satellites, and projecting that the market for remote sensing will reach $4.6 billion by 2026); Mariel Borowitz, *War in Ukraine Highlights the Growing Strategic Importance of Private Satellite Companies – Especially in Times of Conflict*, FUTURE US (Aug. 29, 2022), https://www.space.com/ukraine-war-strategic-importance-private-satellites [https://perma.cc/DEU9-FZQE] (archived Sept. 25, 2023) (identifying the surge in commercial remote sensing satellites, from eleven in 2006 to over 500 in 2022); Igor Moric, *How Commercial Satellite Imagery Could Soon Make Nuclear Secrecy Very Difficult – If Not Impossible*, BULL. ATOMIC SCIENTISTS (July 5, 2022), https://thebulletin.org/2022/07/how-commercial-satellite-imagery-could-soon-make-nuclear-secrecy-very-difficult-if-not-impossible/ [https://perma.cc/QS3S-Q45G] (archived Sept. 25, 2023); *What Is Remote Sensing?*, NAT'L AERONAUTICS & SPACE ADMIN., https://www.earthdata.nasa.gov/learn/backgrounders/remote-sensing [https://perma.cc/8J2X-NZ79] (archived Sept. 25, 2023) (describing types of remote sensing satellites and their applications); *What Is Remote Sensing and What Is It Used For?*, U.S. GEOLOGICAL SURV., https://www.usgs.gov/faqs/what-remote-sensing-and-what-it-used [https://perma.cc/DK93-6UFH] (archived Sept. 25, 2023); *How Remote Sensing Satellites Work*, DRAGONFLY AEROSPACE (May 3, 2022), https://dragonflyaerospace.com/how-remote-sensing-satellites-works/ [https://perma.cc/M7QL-M5PX] (archived Sept. 25, 2023); Debra Werner, *Blue Canyon Technologies to Build Tomorrow.io Microwave Satellites*, SPACENEWS (Aug. 10, 2022, https://spacenews.com/blue-canyon-tomorrow-io/ [https://perma.cc/Y5A6-JJ5M] (archived Sept. 25, 2023) (discussing planned constellation of weather satellites using orbiting radar and microwave sounders); Henk H.F. Smid, *An Analysis of Chinese Remote Sensing Satellites*, SPACE REV. (Sept. 26, 2022), https://www.thespacereview.com/article/4453/1 [https://perma.cc/N2H7-CGK2] (archived Sept. 26, 2023) (analyzing several different types of Earth sensing satellites operated by Chinese military and private companies with projections for rapidly increasing numbers); Sandra Erwin, *With Starshield, SpaceX Readies for Battle*, SPACENEWS (Jan. 19, 2023), https://spacenews.com/with-starshield-spacex-readies-for-battle/ [https://perma.cc/RWM2-BHZK] (archived Sept. 26, 2023) (discussing SpaceX's planned entry into the market for Earth-observing satellites).

has roughly 200 high-resolution spacecraft in orbit providing multi-spectral data for multiple commercial applications,[47] and Spire has over 100.[48]

Within the realm of national security, the US government has recognized strategic value in creating its own large, diverse swarms of small LEO satellites to succeed (or to complement) the legacy systems that featured relatively small numbers of "sitting duck" leviathans, and to establish a "hybrid" space architecture.[49] In pursuit of a resilient satellite ecosystem, the US military and intelligence community are developing a robust structure of dispersed orbiters, exploiting different

47. PLANET LABS PBC, https://www.planet.com/ [https://perma.cc/HC2W-SFNS] (archived Sept. 25, 2023); *Planetscope - Dove Satellite Constellation*, SATELLITE IMAGING CORP., https://www.satimagingcorp.com/satellite-sensors/other-satellite-sensors/dove-3m/ [https://perma.cc/3PVW-Y5BZ] (archived Sept. 25, 2023) (reporting 2021 and 2022 launches of SuperDove high-resolution satellites operating in eight spectral bands, bringing the on-orbit fleet to roughly 200 satellites); *see also Top Remote Sensing Companies*, VENTURERADAR, https://www.ventureradar.com/keyword/Remote%20Sensing [https://perma.cc/VLJ3-9F4T] (archived Sept. 25, 2023) (identifying many private firms operating or developing remote sensing satellites); *Mega-Constellation Satellites on the Horizon*, DET NORSKE VERITAS GRP, https://www.dnv.com/to2030/technology/mega-constellation-satellites-on-the-horizon.html [https://perma.cc/GMN5-DZPV] (archived Sept. 25, 2023).

48. SPIRE, https://spire.com/ [https://perma.cc/Y5RW-PSG3] (archived Sept. 25, 2023); *see also* Zhang, Cai, Xue, Xue & Ca, *supra* note 10, at 3 (describing several other constellations of private LEO satellites for Earth monitoring); Andrew Jones, *Chinese Commercial Remote Sensing Satellite Firm to Double Size of Constellation*, SPACENEWS (Oct. 28, 2022), https://spacenews.com/chinese-commercial-remote-sensing-satellite-firm-to-double-size-of-constellation/ [https://perma.cc/K7UM-BVYR] (archived Sept. 25, 2023) (private Chinese company planning to orbit 300 remote sensing satellites by 2025).

49. Jeanne Dailey, *AFRL's New Lab to Accelerate Hybrid Space Architecture*, AIR FORCE RSCH. LAB'Y (Apr. 21, 2022), https://afresearchlab.com/news/afrls-new-lab-to-accelerate-hybrid-space-architecture/ [https://perma.cc/5KYR-SHCQ] (archived Sept. 25, 2023) (describing government plans for more rapid development of large and small satellites as part of a hybrid architecture); NAT'L ACADS. OF SCIS., ENG'G, & MED., LEVERAGING COMMERCIAL SPACE FOR EARTH AND OCEAN REMOTE SENSING 4 (2022) [hereinafter LEVERAGING COMMERCIAL] (discussing Department of Defense's pursuit of a hybrid space architecture, combining procurement of department-unique satellite systems with reliance on commercial operations); *Hybrid Space Architecture Statement of Principles*, SMALL SAT. ALL., http://smallsatalliance.org/wp-content/uploads/2020/04/Hybrid-Architecture-Statement-of-Principles-v21.pdf [https://perma.cc/M5G5-82RS] (archived Sept. 25, 2023); OLSON, BUTOW, FELT & COOLEY, *supra* note 46, at 49–57 (discussing hybrid space communications network).

altitudes and inclinations,[50] as well as establishing diverse public-private partnerships to own, operate, and use the systems.[51]

Many of these plans are still tentative, of course, dependent upon financing, evolving markets, and disruptive technology; many of the announced ambitions will fail. But it seems safe to predict that the coming decade will see thousands, and then tens of thousands, of new spacecraft, affiliated with multiple governments and corporations, flying all sorts of missions, through widely varying LEO orbital pathways.[52] Financial signs of this near-term future are abundant: by

---

50. Assistant Secretary of Defense for Homeland Defense & Global Security, A White Paper on Space Domain Assurance: A Resilience Taxonomy (Sept. 2015), https://man.fas.org/eprint/resilience.pdf [https://perma.cc/XN9Y-55DG] (archived Sept. 29, 2023); ELBRIDGE COLBY, FROM SANCTUARY TO BATTLEFIELD: A FRAMEWORK FOR A U.S. DEFENSE AND DETERRENCE STRATEGY FOR SPACE 14 (Ctr. for a New Am. Sec. ed., Jan. 27, 2016), https://www.cnas.org/publications/reports/from-sanctuary-to-battlefield-a-framework-for-a-us-defense-and-deterrence-strategy-for-space [https://perma.cc/8ZYU-4GHT] (archived Sept. 29, 2023) [hereinafter White Paper]; LUC H. RIESBECK, ROGER C. THOMPSON & JOSEF S. KOLLER, THE FUTURE OF THE NIGHT SKY: LIGHT POLLUTION FROM SATELLITES 2 (Aerospace Ctr. for Space Pol'y and Strategy ed., Mar. 2020), https://csps.aerospace.org/sites/default/files/2021-08/Riesbeck_SatLight Pollution_03122020.pdf [https://perma.cc/7C4E-ZSK6] (archived Sept. 29, 2023); Courtney Albon, *US Space Force Plan for Rapid Satellite Launches May Finally Take Off*, DEFENSE NEWS (Jul. 12, 2022), https://www.c4isrnet.com/battlefield-tech/space/2022/07/12/us-space-force-plan-for-rapid-satellite-launches-may-finally-take-off/ [https://perma.cc/7NLN-KF5L] (archived Sept. 29, 2023); Theresa Hitchens, *Space Force Phasing Out Missile Warning from GEO, Will Focus on Lower Orbits*, DEFENSE NEWS (Sept. 21, 2022), https://breakingdefense.com/2022/09/space-force-phasing-out-missile-warning-from-geo-will-focus-on-lower-orbits/ [https://perma.cc/X9W8-PNZ8] (archived Sept. 29, 2023) (reporting U.S. military plans to phase out reliance upon the small number of high-altitude satellites for monitoring enemy missiles and controlling U.S. missile defense, in favor of proliferated LEO constellations).

51. LEVERAGING COMMERCIAL, *supra* note 49 (studying opportunities for various public-private partnerships in creating and operating small satellites); Sandra Erwin, *DoD Seeks Ideas for Connecting Government and Commercial Satellites*, SPACE NEWS (Oct. 1, 2021), https://spacenews.com/dod-seeks-ideas-for-connecting-government-and-commercial-satellites/ [https://perma.cc/648F-W8GA] (archived Sept. 26, 2023); KAREN JONES, PUBLIC-PRIVATE PARTNERSHIPS: STIMULATING INNOVATION IN THE SPACE SECTOR, (Aerospace Corp. ed. Apr. 2018), https://csps.aerospace.org/sites/default/files/2021-08/Partnerships_Rev_5-4-18.pdf [https://perma.cc/NL2N-5A3B] (archived Sept. 26, 2023); EXEC. OFFI. OF THE PRESIDENT, NATIONAL LOW EARTH ORBIT RESEARCH AND DEVELOPMENT STRATEGY (Mar. 2023), https://www.whitehouse.gov/wp-content/uploads/2023/03/NATIONAL-LEO-RD-STRATEGY-033123.pdf [https://perma.cc/ZM3F-DT9B] (archived Sept. 26, 2023) (emphasizing the possibilities for public-private collaborations in LEO); U.S. GOV'T ACCOUNTABILITY OFF., GAO-22-106106, NAT'L SEC. SPACE: ACTIONS NEEDED TO BETTER USE COMMERCIAL SATELLITE IMAGERY AND ANALYTICS (2022).

52. 2020 Workshop, *supra* note 3, at 28. *See* Jeff Hecht, *Will Satellites Cripple Ground-Based Astronomy?*, OPTICS & PHOTONICS NEWS 26, 33 (2021) (noting that the predicted number of satellite launches fluctuates, as many corporate plans can get altered suddenly); Foust, *Criticize*, *supra* note 45 (quoting space industry experts as anticipating that many of the exuberant filings for large satellite constellations will not actually be implemented).

some estimates, the global space economy now exceeds $450 billion annually, and is rapidly growing.[53] If anything like the current plans come to fruition, a future observer at almost any point on Earth would have some 5000 satellites in the field of view at all times.[54] ·

Notably, many of the ubiquitous low-cost satellites will have only limited capability for maneuvers once deployed into orbit.[55] Many will stay in space long past their functional lifetimes—a LEO small satellite may be operational for perhaps five years, but current international standards do not require deorbit until twenty-five years thereafter.[56] The congestion of the LEO domain, and the accompanying

53. Space Foundation Editorial Team, *Space Foundation Releases the Space Report 2022 Q2 Showing Growth of Global Space Economy*, SPACE FOUND. (July 27, 2022), https://www.spacefoundation.org/2022/07/27/the-space-report-2022-q2/ [https://perma.cc/H8RJ-FSZS] (archived Sept. 29, 2023) (citing $469 billion in space revenue in 2021, reflecting 6.4% growth since 2020); Michael Sheetz, *The Space Economy Grew at Fastest Rate in Years to $469 Billion in 2021, Report Says*, CNBC (July 27, 2022), https://www.cnbc.com/2022/07/27/space-economy-grew-at-fastest-rate-in-years-in-2021-report.html [https://perma.cc/M4JJ-E9DX] (archived Sept. 27, 2023).

54. JASON, *supra* note 10, at 9.

55. *See* Jeff Foust, *NASA Outlines Concerns about Starlink Next-Generation Constellation in FCC Letter*, SPACE NEWS (Feb. 9, 2022), https://spacenews.com/nasa-outlines-concerns-about-starlink-next-generation-constellation-in-fcc-letter/ [https://perma.cc/Y47M-SXTZ] (archived Sept. 27, 2023) (reporting that SpaceX claims a "zero risk" of collisions, due to Starlink satellites' maneuverability, but NASA doubts the effectiveness of the autonomous collision avoidance capability for a constellation of such size); Tereza Pultarova, *SpaceX Starlink Satellites Had to Make 25,000 Collision-Avoidance Maneuvers in Just 6 Months – and It Will Only Get Worse*, SPACE.COM (July 6, 2023), https://www.space.com/starlink-satellite-conjunction-increase-threatens-space-sustainability [https://perma.cc/LT4B-RZRN] (archived Sept. 27, 2023) (noting that Starlink's autonomous collision-avoidance system performed 25,299 collision-avoidance maneuvers between December 1, 2022 and May 31, 2023); NASA FCC letter, *supra* note 30, at 1–2; *Space Sustainability*, SPACEX (May 7, 2022), https://www.spacex.com/updates/ [https://perma.cc/KVD5-RS2G] (archived Sept. 29, 2023); *SpaceX's Approach to Space Sustainability and Safety*, SPACEX (Feb. 22, 2022), https://www.spacex.com/updates/ [https://perma.cc/KVD5-RS2G] (archived Sept. 29, 2023) (describing Starlink satellites' automatic collision avoidance system); YOUNG & THADANI, *supra* note 39, at 18–19 (discussing collision avoidance systems of several constellations); Fed. Commc'ns Comm'n, FFCC 21–48, In The Matter Of Space Expl. Holdings, Llc, Request For Modification Of The Authorization For The SpaceX Ngso Satellite System, 34–38 (2021) [hereinafter FCC 2021 Order], ; FCC 2022 Order, *supra* note 30, at 39–41; *Our Constellation*, PLANET, https://www.planet.com/our-constellations/ [https://perma.cc/DZY2-6B24] (archived Sept. 29, 2023) (noting that the SkySats do have a propulsion system, but the more numerous Dove satellites do not); *Background*, INT'L ASTRONOMICAL UNION CENTRE FOR THE PROT. OF THE DARK AND QUIET SKY FROM SATELLITE CONSTELLATION INTERFERENCE [hereinafter IAU Background], https://cps.iau.org/background/ [https://perma.cc/G5BM-SYQA] (archived Sept. 29, 2023) (noting numbers of maneuverable and non-maneuverable active satellites over time).

56. *Space Sustainability*, SPACEX, May 7, 2022 [https://perma.cc/KVD5-RS2G] (archived Sept. 29, 2023); *SpaceX's Approach to Space Sustainability and Safety,* SPACEX (Feb. 22, 2022), https://www.spacex.com/updates/ (discussing SpaceX's plan for more timely deorbit of Starlink satellites after their useful life ends) [https://perma.cc/KVD5-RS2G] (archived Sept. 29, 2023); FCC Mitigation of Orbital Debris in the New Space Age,

persistent dangers of collisions and exponentially growing avalanches of fast-flying space debris, will be inevitable.[57]

IV. THE PROBLEM

The intersection of these two vectors—the established routines of ground- and space-based astronomy versus the surge in LEO satellites—presents serious problems of visibility and radio interference, which are only now beginning to be recognized and for which effective, durable solutions have yet to be created.[58]

A. *Optical Astronomy*

For an optical telescope, gazing through the night at the distant skies, the transit of a light-reflecting satellite will leave a fuzzy high-

---

47 C.F.R. §§ 5, 97 (2021) [hereinafter FCC Fact Sheet] (discussing the 25-year benchmark). The FCC has recently adopted a new "Five Year Rule," requiring quicker de-orbit of LEO satellites that are licensed in the United States or that serve U.S. markets, to be effective in two years. Announcement on FCC Adoption of New '5-Year Rule' for Deorbiting Satellites to Address Growing Risk of Orbital Debris, FCC NEWS (Sept. 29, 2022); Jeff Foust, *FCC Approves New Orbital Debris Rule*, SPACE NEWS (Sept. 29, 2022), https://spacenews.com/fcc-approves-new-orbital-debris-rule/ [https://perma.cc/6KWQ-6XL2] (archived Sept. 29, 2023).

57. *See* Ralph Cooney, *Harpoons, Robots, and Lasers: How to Capture Defunct Satellites and Other Space Junk and Bring It Back to Earth*, SPACE REV. (Sept. 19, 2022), https://www.thespacereview.com/archive/4449-1.html [https://perma.cc/36B8-5EHV] (archived Sept. 29, 2023) (asserting that about 60% of the satellites currently in orbit are now out of order). The accelerating problem of space debris is largely beyond the scope of this Article, but it will pose a major challenge for sustainable space operations. In the worst scenario, excessive congestion of space leads eventually to collisions between space objects, which create uncontrolled, fast-flying fragments, and those fragments will sooner or later collide with other space objects, leading to a cascade of further debris creation, rendering broad swaths of space unusable for many years, a condition known as the Kessler Syndrome. *See* Jakub Drmola & Tomas Hubik, *Kessler Syndrome: System Dynamics Model*, 44–45 SPACE POL'Y 29, 29 (2018), https://www.sciencedirect.com/science/article/abs/pii/S0265964617300966 [https://perma.cc/Z8WJ-WTFK] (archived Sept. 29, 2023); *The Megaconstellation Threat*, *supra* note 15, at 10; *FAQ: Frequently Asked Questions*, EUR. SPACE AGENCY (April 2021), https://www.esa.int/Space_Safety/Space_Debris/FAQ_Frequently_asked_questions [https://perma.cc/GK9C-SZ57] (archived Sept. 29, 2023); FCC Fact Sheet, *supra* note 56 (presenting new regulation regarding creation of space debris); Technology Assessment, *supra* note 10, at 38–52. Also note the environmental damage from so many additional space missions. *See* NASA FCC Letter, *supra* note 30, at 1; SATCON2, *supra* note 2, at 111–15, 180 (discussing pollution from space launches, including soot, aluminum, and ozone-endangering particulates); BEISCHL, *supra* note 42, at 16–18; FCC 2021 Order, *supra* note 55, at 32–40.

58. *See* 2021 Workshop, *supra* note 2, at 77 (observing that the negative impact of large constellations of communications satellites "has only recently come to the attention of the astronomical community"); Finnegan, *supra* note 2; BEISCHL, *supra* note 42; DE ZWART & LISK, *supra* note 35.

intensity streak across the observatory's detector (typically a CCD array) and generate a signature white line on the resulting photographic imagery. That indelible slash will obscure any other light sources behind it, altering the response of the affected pixels and degrading the value of the captured information. Simulations suggest that the future satellite population may mean that "[t]ens to hundreds of streaks will potentially appear in every shot," depending on the circumstances.[59] In some cases, the incoming light may generate saturation effects, ruining the entire image, not just the portion behind the streak.[60] Sometimes, a sudden flare of reflected sunlight off a satellite's flat surfaces can generate a brief but intense glint of dazzling light, resulting in an especially bright burst disrupting an electronic photographic image.[61]

---

59. 2020 Workshop, *supra* note 3, at 127. *See also* Przemek Mroz, Angel Otarola, Thomas A. Prince, Richard Dekany, Dmitry A. Duev, Matthew J. Graham, Steven L. Groom, Frank J. Masci, & Michael S. Medford, *Impact of the SpaceX Starlink Satellites on the Zwicky Transient Facility Survey Observations* (Jan. 17, 2022) (unpublished article), https://arxiv.org/abs/2201.05343 [https://perma.cc/W8RC-DGKX] (archived Sept. 29, 2023) (reporting results of a study of archived observations from the Zwicky Transient Facility near San Diego, finding that between November 2019 and September 2021, there were 5301 streaks attributed to the passage of Starlink satellites, rising from fewer than one affected image per night in early 2020 to nearly 20 streaked images per night in the second half of 2021; sometimes, up to 15 satellite streaks marred one image. Nonetheless, the overall fraction of pixels lost was not large, and the facility's science operations have not yet been severely affected); PATRICK SEITZER & J. ANTHONY TYSON, LARGE LEO CONSTELLATIONS, ASTRONOMY, AND MITIGATION (2021, https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/112/SDC8-paper112.pdf [https://perma.cc/N5UA-Z3WE] (archived Sept. 29, 2023) (describing five types of problems that satellite trails pose for observatories' photographic images); SATCON1, *supra* note 6, Appendix C, at 67 ("The satellites that may trail through these images will typically be ten million times as bright as the asteroids that we are trying to discover, and will wipe out long trails in each image, rendering any nearby pixels unusable.").

60. *See* 2020 Workshop, *supra* note 3, at 124; Lawrence, Rawls, Jah, Boley, Vruno, Garrington, Kramer, Lawler, Lowenthal, McDowell & McCaughrean, *supra* note 19, at 430; Hecht, *supra* note 52, at 29 (describing how the use of extremely sensitive detectors to observe ultra-faint light sources makes a telescope especially vulnerable to bright light that can not only saturate a pixel, but also "wipe out the data recorded in a whole column of sensors"); Samantha M. Lawler, Aaron C. Boley & Hanno Rein, *Visibility Predictions for Near-future Satellite Megaconstellations: Latitudes Near 50 Will Experience the Worst Light Pollution*, 163 ASTRONAUTICAL J. 11, 21 (2022); *The Megaconstellation Threat*, *supra* note 15, at 15 (discussing how a bright light will not only saturate pixels in one part of an image, and several pixels on either side, but also generate "ghost" artifacts elsewhere in the image, and even create an "afterimage" in the next picture); BYERS & BOLEY, *supra* note 34, at 93; J. Anthony Tyson, *Mitigation of LEO Satellite Brightness and Trail Effects on the Rubin Observatory LSST*, 160 ASTRONOMICAL J. 5, 5 (2020) https://iopscience.iop.org/article/10.3847/1538-3881/abba3e/pdf [https://perma.cc/SD53-6LEX] (archived Sept. 29, 2023) (reporting that astronomers and satellite designers were initially surprised by the brightness of the Starlink satellites and how damaging their effects were).

61. 2020 Workshop, *supra* note 3, at 132–33; SATCON1, *supra* note 6, at 19, 89 (discussing the problem of varying flares and glints of reflected light from satellite surfaces); RIESBECK, THOMPSON & KOLLER, *supra* note 50, at 4; Hainaut & Williams, *supra* note 17, at 5–7.

In addition to the trails of reflected light attributable to a particular satellite, the vast multiplication of objects in space is contributing to a new general background brightness in the night sky, which is cumulatively degrading the ability to detect faint, remote points of light of great interest.[62] By some measures, the scattering of sunlight from existing LEO satellites and debris may have already brightened the diffuse natural sky glow by 10%.[63] Moreover, even when a satellite is not illuminated by the sun (so it does not leave a light streak across a telescope's image), the satellite still blocks the view of phenomena behind it, and can confuse interpretation of the occluded space.[64]

These types of human-caused interference have always been problematic for optical astronomy. The passage of satellites at any altitude will mar an image; large pieces of light-reflective space debris can pose similar difficulties. Even overflying aircraft can intrude.[65] But

62. SATCON2, *supra* note 2, at 86; Miroslav Kocifaj, Frantisek Kundracik, John C. Barentine & Salva Bara, *The Proliferation of Space Objects Is a Rapidly Increasing Source of Artificial Night Sky Brightness*, 504 Monthly Notices of the Royal Astronomical Soc'y L40 (Apr. 2, 2021), https://www.unoosa.org/documents/pdf/psa/activities/2021/DQS2021/Day3/Sess12/D3S12_4_SCWG_BARENTINE.pdf [https://perma.cc/9G6Q–X7ZH] (archived Sept. 29, 2023) (observing that a space object that is, by itself, below the threshold of detection as a discrete source of light will still contribute to the general ambient light in the sky, diminishing the productivity of optical telescopes); 2021 Workshop, *supra* note 2, at 264–66; Bassa, Hainaut & Galadi-Enriquez, *supra* note 44, at 9.

63. *See* Richard F. Green, Christian B. Luginbuhl, Richard J. Wainscoat & Dan Duriscoe, *The Growing Threat of Light Pollution to Ground-Based Observatories*, 30 ASTRONOMY & ASTROPHYSICS REV. 1 (2022); Kocifaj, Kundracik, Berentine & Bara, *supra* note 62; SATCON2, *supra* note 2, at 216; Technology Assessment, *supra* note 10, at 31 (arguing that the effect of satellite proliferation on diffuse sky brightness is expected to be minimal, but the effect of many pieces of small orbital debris could be more significant); John C. Barentine, Aparna Venkatesan, Jessica Heim, James Lowenthal, Miroslav Kocifaj & Salvador Bará, *Aggregate Effects of Proliferating Low-Earth-Orbit Objects and Implications for Astronomical Data Lost in the Noise*, 7 NATURE ASTRONOMY 252, 253 (2023); RIESBECK, THOMPSON & KOLLER, *supra* note 50, at 5 (describing several highly-reflective satellites); 2021 Report, *supra* note 25, at ¶ 39.

64. Lawler, *supra* note 60, at 13; Boyle, 2023, *supra* note 45 (reporting that an observatory's software has a difficult time differentiating between artificial satellites and natural phenomena of interest); Tereza Pultarova, *The Oldest Gamma-Ray Burst Ever Discovered Was Just a Piece of Space Junk*, SPACE.COM (Oct. 7, 2021), https://arxiv.org/pdf/2109.04328.pdf [https://perma.cc/SQM2-LX34] (archived Sept. 29, 2023); Barentine, Venkatesan, Heim, Lowenthal, Kocifaj & Bará, *supra* note 63, at 253.

65. RIESBECK, THOMPSON & KOLLER, *supra* note 50, at 2–4; Jonathan C. McDowell, *The Low Earth Orbit Satellite Population and Impacts of the SpaceX Starlink Constellation*, 892 Astrophysical J. Letters 2 (Apr. 1, 2020) (recalling that in earlier years, when the satellite population was lower, interference with astronomy was characterized as a nuisance, rather than a problem); Rafael Moro-Aguilar, *Megaconstellations of Satellites and Their Impact on Astronomy: Exploring the Role of Article IX of the Outer Space Treaty*, 73rd INT'L ASTRONAUTICAL CONG.INT'L

the challenge has suddenly become much more severe in just the past four years, rising from the level of a "nuisance" into a "problem" and then a "threat." Many astronomers were initially caught by surprise by the sudden surge in satellite numbers and brightness. As the enormous swarms of illuminated LEO satellites proliferate, the predicament will greatly intensify.[66] The problem is of global scope, with observatories

---

ASTRONAUTICAL CONG. 2022 (2022) [hereinafter Moro, *Exploring the Role*] (noting that as early as 1961, astronomers were concerned about the adverse effects of space activities).

66. Seitzer & Tyson, *supra* note 59 (observing that the new LEO satellites now being launched are "brighter than the vast majority of everything in orbit today" as well as being more numerous); McDowell, *supra* note 65, at 1 (noting that when SpaceX began its initial Starlink launch in 2019, professional and amateur astronomers immediately expressed surprise and concern); Alexandra Witze, *Astronomers Push for Global Debate on Giant Satellite Swarms*, NATURE (July 16, 2021), https://www.nature.com/articles/d41586-021-01954-4 [https://perma.cc/FD54-CX6M] (archived Sept. 29, 2023) (reporting that astronomers were caught by surprise in 2019 when they first saw the brightness of Starlink satellites); Stephen Clark, *SpaceX to Debut Satellite-Dimming Sunshade on Next Starlink Launch*, ASTRONOMY NOW (May 5, 2020), https://astronomynow.com/2020/05/05/spacex-to-debut-satellite-dimming-sunshade-on-next-starlink-launch/ [https://perma.cc/F425-PV6L] (archived Sept. 29, 2023) (noting that people were startled by the brightness of the Starlink satellites). *But see* Shara & Johnston, *supra* note 30 (anticipating in 1986 the problem of satellites interfering with space-based telescopes). *See also* Tariq Malik, *SpaceX Rocket Launches BlueWalker 3, the Largest Commercial Communications Array Ever, and Aces Record 14th Landing*, SPACE.COM (Sept. 10, 2022), https://www.space.com/spacex-bluewalker-3-starlink-satellites-launch-success [https://perma.cc/9CXF-R8L6] (archived Sept. 29, 2023) (reporting the launch of a very large BlueWalker LEO communications satellite, the first of a projected 100 in the series, which is foreseen as becoming the brightest object in the night sky except for the Moon, posing special problems for astronomy); Jonathan O'Callaghan, *Huge Satellite Could Outshine All Stars and Planets in the Night Sky*, NEW SCIENTIST (Sept. 9, 2022), https://www.newscientist.com/article/2337336-huge-satellite-could-outshine-all-stars-and-planets-in-the-night-sky/ [https://perma.cc/M8TM-BTWL] (archived Sept. 29, 2023); Brad Young, *Analyzing the Deployment of BlueWalker 3*, SPACE REV. (Dec. 5, 2022), https://www.newscientist.com/article/2337336-huge-satellite-could-outshine-all-stars-and-planets-in-the-night-sky/ [https://perma.cc/N7KU-5HQ9] (archived Sept. 29, 2023) (addressing the damage that would be done by the planned constellation of 168 such large, vivid satellites); BYERS & BOLEY, *supra* note 34, at 117–18 (emphasizing that the rocket bodies used to transport satellites into space often linger in orbit long after launch, and these spent bodies will also reflect sunlight, interfering with astronomy; in fact, since the rockets tend to be large and tumbling, they can pose an especially significant problem).

Another dimension of the potential problem arises from some large telescopes' use of "adaptive optics," through which an intense laser beam is directed into space to help measure atmospheric turbulence and compensate for it by calibrating the telescope to avoid blurring images. These lasers might unintentionally interfere with or damage a satellite passing directly overhead, so the U.S. Department of Defense has established a Laser Clearing House, which instructs military laser operators to switch off or redirect their lasers when a potentially harmful interaction could occur. Currently, a major telescope is asked to briefly turn off its laser a few to ten times per night, but if future large constellations emerge, the lasers may be required to be deconflicted so frequently that the adaptive optics would become useless. JASON, *supra* note 10, at 45–49; Michael Lucibella, *Air Force Restrictions Impact Adaptive Optics*, 18 APS NEWS (Oct. 2009), https://www.aps.org/publications/apsnews/200910/optics.cfm [https://perma.cc/H6Z5-

around the world all concerned about the anthropogenic loss of effective telescope operations.[67]

The altitude at which a satellite orbits can have different types of effects on this interference. First, other factors being equal, the farther away a satellite is, the less bright it will appear to the observer, so the less harm it will do to a photographic image. Moreover, a constellation at a lower orbit will require more satellites in order to provide the same panoramic coverage of Earth that can be accomplished by fewer satellites (and fewer points of interference with astronomy) at higher altitude. On the other hand, and more important to the astronomers, a satellite orbiting at higher altitude will catch the sun's rays for a longer period of time each evening, before falling into the Earth's shadow; it will accordingly provide a source of unwanted illumination for more hours at a time. Also, at higher altitude, a satellite moves more slowly across the sky, so it will create a more prolonged streak on the imagery, and it will ordinarily stay in orbit for a longer duration before degrading back to Earth (including for many years after its operational life expires), so it will pose a more enduring problem.[68]

DWNG] (archived Sept. 29, 2023) (government regulations restrict observatories' use of laser adaptive optics, in order to protect satellites from interference); Robert J. Volio, *Laser Tagged – How the JSpOC Manages Laser Deconfliction*, VANDENBURG SPACE FORCE BASE (Aug. 19, 2016), https://www.vandenberg.spaceforce.mil/News/Features/Display/Article/920559/laser-tagged-how-the-jspoc-manages-laser-deconfliction/ [https://perma.cc/3XJV-C5GR] (archived Sept. 29, 2023).

67. Brendan Cole, *Light from Elon Musk's Starlink Satellites Ruins Space Photos, Says Russian Government Agency*, NEWSWEEK (Feb. 28, 2020), https://www.newsweek.com/elon-musk-starlink-russia-united-nations-satellites-1489708 [https://perma.cc/F7Z2-B8PU] (archived Sept. 29, 2023) (Russian Academy of Sciences expresses concern that reflected sunlight could corrupt 30–40% of astronomical images); Fengyu Wang, Protection of the Dark and Quiet Skies in China, Presentation at U.N. Office of Outer Space Affairs Symposium (Feb. 15, 2022), https://www.unoosa.org/documents/pdf/copuos/stsc/2022/Part2-CNSA.pdf [https://perma.cc/3J9X-RBQ2] (archived Sept. 29, 2023) (addressing China's efforts to protect observatories from interference); Joshua Sokol, *Study Finds Nowhere on Earth Is Safe from Satellite Light Pollution*, SCI. (Mar. 28, 2021), https://www.science.org/content/article/study-finds-nowhere-earth-safe-satellite-light-pollution [https://perma.cc/LMM2-S69E] (archived Nov. 14, 2023).

68. 2020 Workshop, *supra* note 3, at 144 (explaining that a satellite at higher altitude will be illuminated for more hours per night, and will appear higher in the sky; in addition, such a satellite will appear more "in focus" to telescopes on the ground, resulting in a brighter trail on an image); JASON, *supra* note 10, at 37–39 (noting that when the anticipated OneWeb constellation is complete, there will be over 500 satellites visible from any spot on Earth even at midnight, and when satellites orbiting at 1000 kilometers altitude fail, they will pose a "semi-permanent population of non-maneuverable space junk," compounding the problem of debris and collisions); 2021 Report, *supra* note 25, at ¶ 40; Alexandra Witze, *How Satellite Swarms Pose a Rising Threat to Astronomy*, NATURE (June 9, 2022), https://www.nature.com/articles/d41586-022-01420-9 [https://perma.cc/5HD3-GFSG] (archived Sept. 29, 2023) (reporting that half of the operational OneWeb satellites were only slightly brighter than astronomers had wanted).

For example, the Starlink satellites, orbiting at approximately 550 kilometers above Earth, will typically be illuminated by the sun for all but about four hours per night during the summer. The problem is exacerbated for several days or weeks immediately after a new batch of the Starlink satellites is launched, while they fly in a very low orbit before they are dispersed to their operational altitude and locations.[69] In contrast, the OneWeb constellation circles at approximately 1200 kilometers; each of those satellites will appear less bright from Earth, but they will be visible by observatories for several additional hours per night during the winter and will be in view all night long during the summer.[70]

As a class, remote sensing satellites will pose many of the same sorts of interference problems as communications satellites, but typically they are less acute. For one thing, reconnaissance satellites tend to be smaller, and therefore less prone to reflect vivid sunlight; they also transmit data much less frequently, and so pose less impediment for radio astronomy.[71] But most important are the numbers: current and projected constellations of Earth monitoring

---

69. Starlink satellites are launched in a somewhat unusual fashion. Instead of rapidly ascending to their operational altitude, they have typically been inserted into a very low orbit and only gradually (over weeks or months) thrust into the final location. While in the low orbits, the satellites fly in a cluster that appears quite bright – likened to a "string of pearls" – on observatories' photographic images. When the Starlink constellation is complete, about 3–5% of the constellation will be in this low orbit posture, reflecting more than the usual amount of light, at any time. 2020 Workshop, *supra* note 3, at 134; SATCON1, *supra* note 6, Appendix C, at 58–60; Clark, *supra* note 66; *The Megaconstellation Threat*, *supra* note 15, at 5 (also noting that SpaceX's original plans had called for Starlink to be placed in orbits around 1160–1325 kilometers, with some at 335–346 kilometers).

70. LEO satellites will be most visible during the hours just before and after dusk and dawn, but at higher elevations, the satellites will avoid the Earth's shadow for a longer period. SATCON1, *supra* note 6, at 5; 2020 Workshop, *supra* note 3, at 122–24 (during the winter, LEO satellites will reflect sunlight throughout the night; many will be visible with the naked eye and all will be detected by observatories); JASON, *supra* note 10, at 36; RIESBECK, THOMPSON & KOLLER, *supra* note 50, at 5–9; Alexandra Witze, *How Satellite "Megaconstellations" Will Photobomb Astronomy Images*, NATURE, (Aug. 26, 2020), https://www.nature.com/articles/d41586-020-02480-5 [https://perma.cc/MHF3-WU9P] (archived Sept. 29, 2023) (quoting astronomer Tony Tyson saying "There's no place to hide in the middle of the night from such a satellite constellation"); IAU Background, *supra* note 55 (noting numbers of satellites expected to be visible above the horizon in summer nights, varying with satellite altitude); *The Megaconstellation Threat*, *supra* note 15, at 5–6.

71. SATCON2, *supra* note 2, at 210. Regarding comparative sizes of different types of satellites, Dove remote sensing satellites are only 10x10x30 centimeters in size and weigh 5 killigrams. *See Our Constellation*, PLANET, https://www.planet.com/our-constellations/ [https://perma.cc/DVZ6-GUVZ] (archived Sept. 29, 2023). The original Starlink satellites are 2.8 meters long and 1.4 meters wide (not counting their large solar panels) and weigh 573 pounds; the next generation of Starlink satellites will be twice as large. Brian Wang, *SpaceX Starlink Gen2 Satellites Five Times Area of Gen 1*, NEXTBIGFUTURE (June 7, 2022), https://www.nextbigfuture.com/2022/06/s.html [https://perma.cc/AX4H-9AJA] (archived Sept. 29, 2023); *Second Generation*, *supra* note 38.

satellites are much smaller than the looming fleets of communications satellites, and so will generate many fewer occasions for sustained potential interference.[72]

To some extent, it is possible to mitigate the interference problem simply by pointing the telescope away from the overflying spacecraft (or aircraft) and examining a different segment of the sky that is not being afflicted by the reflected light (assuming the celestial objects of interest are to be found there). Astronomers are accustomed to making that type of scheduling accommodation, when the timing and location of the interference are predictable and limited.[73] But some telescopes are deliberately designed to undertake a wide-field survey, rather than being highly directional; in that case, simply looking elsewhere would not suffice.[74] For example, regarding the soon-to-be-operational Vera C. Rubin observatory in remote northern Chile—expected, at a price of nearly one-half billion dollars, to become the state of the art facility for panoramic optical telescopes—30–40 percent of the images acquired (especially near dawn and dusk) may be unusable due to interference from overflying satellites.[75] And in the future, the bevy of proliferating

---

72. SATCON2, *supra* note 2, at 210 (evaluating the light reflectivity of commercial remote sensing satellites); Arun Kumar Sampathkumar, *Space as a Warfighting Domain: Evolving Concerns and Required Solutions*, MILSATMAG (Mar. 2023), https://noirlab.edu/public/media/archives/techdocs/pdf/techdoc033.pdf [https://perma.cc/F2KJ-W5AZ] (archived Sept. 29, 2023) (estimating that 43,425 satellites will be launched in 2022–32, of which 7,673 will be devoted to Earth monitoring).

73. 2020 Workshop, *supra* note 3, at 124 (noting that interference by satellites reflecting sunlight will usually be greatest toward the horizon; to some extent, observatories can avoid that azimuth, but for some collection purposes, that is where they must be directed); SATCON1, *supra* note 6, at 24, 28 66–67 (noting that observations of the sky near the horizon and before total darkness are especially important for planetary defense purposes, detecting potentially hazardous asteroids); RIESBECK, THOMPSON & KOLLER, *supra* note 50, at 9 (noting technical or physical limitations on most telescopes' ability to point to all the possible regions of the visible sky).

74. Telescopes with wide fields of view, such as the forthcoming Vera C. Rubin Observatory (formerly known as the Large Synoptic Survey Telescope (LSST)) in Chile and the Pan-Starrs in Hawaii, scan broad areas of the skies to detect interesting objects or phenomena that are then studied in more detail by other telescopes with a smaller field of view. SATCON1, *supra* note 6, at 18; VERA C. RUBIN OBSERVATORY, IMPACT ON OPTICAL ASTRONOMY OF LEO SATELLITE CONSTELLATIONS 2–3(2020) [hereinafter RUBIN OBSERVATORY] (forecasting that when the projected LEO satellite constellations are complete, nearly every exposure captured by the Rubin Observatory within two hours of sunset or sunrise would be marred by a satellite trail); Technology Assessment, *supra* note 10, at 23–25 (comparing interference effects on narrow-field and wide-field telescopes).

75. *See* 2020 Workshop, *supra* note 3, at 15; Hainaut & Williams, *supra* note 17, at 1, 11 (describing the effect of satellite interference as being "ruinous" for the Rubin Observatory, with 30–50% of exposures impacted during some important observation times); Tyson, *supra* note 60, at 2 (estimating that at twilight, 40–90% of the

satellite networks will populate all areas of the sky simultaneously, eliminating any reliably safe and clean zones or time frames.[76]

Another type of response is to refine the telescope's optical filters or its computer software, to artificially dampen the effects of the offending light. These "smart" digital processing techniques can confine the obstruction to as few pixels as possible in each image, but the data from behind the streaks is still lost—the information blocked by the satellite's passage is not collected or accessible.[77] Another mitigation technique is to acquire multiple, sequential overlapping images of the same field of view and artificially stitch them together to erase the streaks, but this is also an imperfect technique and it does cost more observation time and effort.[78]

Alternatively, or additionally, adjustments can be made to the satellites to reduce the deleterious effects. For example, there are options for making a satellite less reflective: it could be painted a dark

---

observations will have at least one light trail from a satellite);, INDICO, THE LARGE SYNOPTIC SURVEY TELESCOPE (LSST), https://indico.fnal.gov/event/6381/contributions/95749/attachments/62530/74946/LSST_summary.pdf [https://perma.cc/2LQX-PF9H] (archived Sept. 29, 2023) (estimating total system lifetime cost at over $1 billion).

76. *See* discussion, *supra* note 30. As noted, even telescopes based in space are unable to escape the light and noise of other low Earth orbit satellites. NASA scientists fear "there may be a point in the future where LEO could be effectively "closed" to astrophysics because of the high number of satellites." Technology Assessment, *supra* note 10, at 30.

77. Lawler, *supra* note 55, at 11 (noting that computer algorithms can help mitigate some forms of data loss, but cannot retrieve data that was not collected due to interference); Alexandra Witze, *"Unsustainable": How Satellite Swarms Pose a Rising Threat to Astronomy*, NATURE (May 26, 2022), https://www.nature.com/articles/d41586-022-01420-9 [https://perma.cc/6EQK-694C] (archived Sept. 29, 2023) (discussing image-processing methods that can mitigate the effects of satellite trails); SATCON1, *supra* note 6, at 86–87 (finding that the effects of satellite interference may range from a 10–20% increase in required exposure time to a "complete loss of ability to study certain astrophysical problems"); RUBIN OBSERVATORY, *supra* note 74, at 3–4 (discussing loss of data, even after the observatory applies mitigation techniques); Monica Young, *Beyond Starlink: The Satellite Saga Continues*, SKY & TELESCOPE (Jan. 22, 2021), https://skyandtelescope.org/astronomy-news/beyond-starlink-the-satellite-saga-continues/ [https://perma.cc/WTS5-V5ER] (archived Sept. 29, 2023) (quoting astronomers who emphasize that there are limits to how successful the image processing algorithms can be in removing the effects of an intruding satellite and noting that the satellite is forty million times brighter than the objects that a telescope seeks to observe); Rebecca Boyle, *The Threat of Satellite Constellations*, SCIENTIFIC AM. (Feb. 2023), https://www.scientificamerican.com/article/satellite-constellations-are-an-existential-threat-for-astronomy/ [https://perma.cc/3CER-5WNC] (archived Sept. 29, 2023).

78. RIESBECK, THOMPSON & KOLLER, *supra* note 50, at 9–10; HANDBOOK, *supra* note 6, at 70 (noting that observational time is already oversubscribed, with the best telescopes in heavy demand); Lawrence, Rawls, Jah, Boley, Vruno, Garrington, Kramer, Lawler, Lowenthal, McDowell & McCaughrean, *supra* note 19, at 431 (estimating that for radio astronomy, "once the mature Starlink population is in orbit, every observation in the relevant bands will take on average 70% longer."); *The Megaconstellation Threat*, *supra* note 15, at 15–16 (emphasizing that "even with all the careful post-processing available, there is a limit to what can be achieved when the burden of multiple mitigations grows to asphyxiate access to our skies.")

color (but if more sunlight is absorbed by the satellite instead of being reflected, the satellite can become dysfunctionally hot); it could be tilted so it reflects less light (but that reorientation would consume fuel, and could impair performance); [79] or it could be outfitted with a hood or visor (but that raises the weight and cost). SpaceX has sometimes voluntarily deployed these accommodations, such as painting one of the second generation of Starlinks a dull black (denominated as DarkSat) and experimentally equipping several hundred with a sun-shielding screen (VisorSat) that mitigates reflections.[80]

More recently, however, SpaceX stopped employing the visor, because it interfered with the next-generation mechanism for satellite-to-satellite laser communications. Instead, SpaceX has switched to other adaptations,[81] and, in January 2023, SpaceX and the National

---

79. 2020 Workshop, *supra* note 3, at 132–33 (discussing the effectiveness of small changes in the satellite's attitude, which can reduce the incidence of reflected glare); Witze, *supra* note 77.

80. Clark, *supra* note 66; 2020 Workshop, *supra* note 3, at 30 (assessing that "Limited observations of DarkSat and VisorSat indicate that the brightness-reduction mitigation measures implemented in the modified designs are effective but do not achieve the recommendation brightness goals stated in this report in all operational phases and geometries."), at Appendix D, at 232 (noting that DarkSat was launched on January 7, 2020 and the first VisorSat on June 4, 2020; additional Starlink satellites with the same sun-visor technology were launched starting on August 7, 2020), 247 (concluding that the DarkSat and VisorSat mitigations, along with Starlink's efforts to align the satellites better to achieve less reflection, did diminish their apparent brightness, but not sufficiently to meet recommended standards), 141–43 (describing DarkSat and VisorSat); Anthony Mallama, The Brightness of VisorSat-Design Starlink Satellites (Jan. 2, 2021) (unpublished manuscript), https://arxiv.org/ftp/arxiv/papers/2101/2101.00374.pdf [https://perma.cc/9C7Q-UW5K] (archived Sept. 29, 2023) (finding that on average the VisorSat is 31% as bright as previous Starlink satellites); J. Tregloan-Reed, *First Observations and Magnitude Measurement of Starlink's Darksat*, 637 ASTRONOMY & ASTROPHYSICS 1 (Apr. 23, 2020), https://www.aanda.org/articles/aa/pdf/2020/05/aa37958-20.pdf [https://perma.cc/5LFJ-ZNW8] (archived Sept. 29, 2023) (reporting that the first DarkSat was two times dimmer than the standard Starlink satellite, but to meet the requirements for avoiding interference with large telescopes, it would have to be fifteen times dimmer than the usual Starlink); Tyson, *supra* note 60, at 11 (saying that DarkSat and VisorSat can suppress many of the adverse effects of Starlink, and calling them "a promising development").

81. SpaceX, Space Sustainability, May 7, 2022 (discussing new mechanisms for reducing satellite brightness, including paint, visors, stickers, and altering the satellite's angle toward the Earth); White Paper, *supra* note 50 (describing brightness mitigation measures on the second generation of Starlink satellites, including dielectric mirror film (designed to direct the solar reflections away from Earth), use of low-reflectivity black paint on particular components, and pointing the solar panels away from the sun at key times); *Second Generation*, *supra* note 38; Lawler, *supra* note 55, at 6 (observing considerable variation in the brightness of VisorSats, suggesting that perhaps there may be inconsistencies in the visors or their effectiveness is very sensitive to the precise orientation in space); GRACE HALFERTY, PHOTOMETRIC CHARACTERIZATION AND TRAJECTORY ACCURACY OF STARLINK SATELLITES: IMPLICATIONS FOR GROUND-BASED

Science Foundation reached an agreement on further measures to protect astronomy.[82]

B. *Radio Astronomy*

Radio telescopes are even less adaptable than optical observatories. The need to access very faint signals from the most distant reaches of space makes these installations quite vulnerable to anthropogenic radio noise. The uplinks, downlinks, and crosslinks that are at the heart of communications satellite networks pose a major, hard-to-resist problem. Perhaps even worse is remote-sensing satellites' use of high-powered synthetic aperture radars to map the Earth and study its climate; one astronomer assesses that "these beams are like death rays for radio astronomy receivers."[83]

ASTRONOMICAL SURVEYS (Monthly Notices of the Royal Astronomical Society ed. 2022), https://arxiv.org/abs/2208.03226 [https://perma.cc/D228-L4XK] (archived Sept. 29, 2023) (comparing DarkSat, VisorSat and the original Starlink satellites). SpaceX used the visors on hundreds of satellites, but stopped doing so in 2022 because they were incompatible with the satellite optical laser cross-communications links that are featured on the next generations of Starlink satellites to further reduce latency. *See also* Jeff Foust, *Astronomers Renew Concerns About Starlink Satellite Brightness*, SPACE NEWSSPACE NEWS (June 17, 2022), https://spacenews.com/astronomers-renew-concerns-about-starlink-satellite-brightness/ [https://perma.cc/XX26-T7VK] (archived Sept. 29, 2023) (reporting that the new Starlink satellites are brighter than those equipped with visors, and quoting one astronomer saying, "In a real sense, we're going backwards here."); FCC 2022 Order, *supra* note 30, at 47–52 (commending SpaceX's persistent efforts to reduce the brightness of Starlink satellites, but also reporting astronomers' criticisms that the accommodations are insufficient).

82. Jeff Foust, *NSF and SpaceX Reach Agreement to Reduce Starlink Effects on Astronomy*, SPACE NEWS ((Jan. 12, 2023), https://spacenews.com/nsf-and-spacex-reach-agreement-to-reduce-starlink-effects-on-astronomy/ [https://perma.cc/X9VJ-SVQP] (archived Sept. 29, 2023) (reporting the voluntary accord, under which SpaceX would dim its satellites to make them invisible to the naked eye; not transmit when a satellite overflies a major radio observatory; and remove its satellites from the Laser Clearinghouse, so observatories would not have to switch off their adaptive optics when a Starlink flies overhead); *NSF Statement on NSF and SpaceX Astronomy Coordination Agreement*, NAT'L SCI. FOUND. (Jan. 10, 2023), https://new.nsf.gov/news/statement-nsf-astronomy-coordination-agreement [https://perma.cc/35QT-ZUJN] (archived Sept. 29, 2023).

83. Hecht, *supra* note 52, at 34 (quoting astronomer Harvey Liszt). *See also* IAU Background, *supra* note 55 (noting wide range of adverse effects of interference with radio astronomy); *The Megaconstellation Threat*, *supra* note 15, at 16 (assessing that the intensity of a radio signal from a Starlink downlink (disrupting radio astronomy) is fourteen times greater than the glint of visible light from that satellite (disrupting optical telescopes); Tereza Pultarova, *Megaconstellations Like SpaceX's Starlink May Interfere with Search for Life by World's Largest Radio Telescope*, SPACESPACE (Feb. 3, 2022), https://www.space.com/spacex-starlink-affects-search-for-life-radio-observatory [https://perma.cc/DF2N-3HA8] (archived Sept. 29, 2023) (noting interruptions in key radio telescope operations, despite expensive adaptations, due to satellite interference); Technology Assessment, *supra* note 10, at 32–36 (observing that "transmission effects from satellites are not a new problem for radio astronomy," but as the number of LEO satellites increases dramatically, the ability to acquire faint cosmic radio signals will be

The best available accommodation for radio astronomy is through rigid frequency allocation (and enforcement of the management scheme), allowing the satellites to broadcast only on particular wavelengths, while preserving other channels for undisturbed sensitive astronomical collection. Radio astronomy has a long tradition of coping with these types of interference, but as the demand for communications and other services continues to mushroom, those restrictions could become further squeezed.[84] In the United States, regulation of the radio spectrum for space functions is accomplished principally through the licensing procedures of the Federal Communications Commission; internationally, the International

---

jeopardized); 2020 Workshop, *supra* note 3, at 180 (satellite radars are powerful enough to destroy a ground-based receiver). The 2023 agreement between SpaceX and the National Science Foundation also contains provisions to protect radio quiet zones and the portions of the spectrum reserved for radio astronomy. *See NSF and SpaceX Finalize Radio Spectrum Agreement*, AUI (Jan. 10, 2023), https://aui.edu/nsf-and-spacex-finalize-radio-spectrum-coordination-agreement/ [https://perma.cc/M247-KJTN] (archived Sept. 29, 2023).

84. 2020 Workshop, *supra* note 3, at 37, 165–67; 2021 Workshop, *supra* note 2, at 272–73; Peel, *supra* note 19; 2021 CRP, *supra* note 6, at 4; JASON, *supra* note 10, at 19 (noting that a license from the Federal Communications Commission is required for a satellite to serve the lucrative U.S. market, and this procedure has enabled effective regulation of the radio frequencies used, so astronomy can enjoy some degree of protection, but a satellite that is launched outside the United States and Europe, and that does not intend to serve those markets, can escape that regulation), 49 (discussing radio frequency regulation nationally by the FCC and the National Telecommunications and Information Administration, and internationally by the International Telecommunications Union (ITU), but concluding that "this regulatory framework does not seem to be sufficient to protect radio astronomy in the era of large constellations of communications satellites"); HANDBOOK, *supra* note 6, at 13–14 (describing the allocation of primary and secondary frequency bands; generally, a primary service may interfere with a secondary user, but not vice-versa), 16–17 (noting that radio astronomy attempts to access extremely weak signals and cannot arbitrarily choose which frequencies to study, so it is very vulnerable to interference and it experiences great difficulty in sharing frequency bands); 2021 Workshop, *supra* note 2, at 80 (reporting that approximately 2% of the usable radiofrequency spectrum is primarily allocated to radio astronomy); 2021 Workshop, *supra* note 2, at 221 (noting that if the United States were to adopt federal regulations regarding the adverse effects of satellite constellations on astronomy, "the FCC would be the primary and logical source from which they would emanate"); 2021 CRP, *supra* note 6, at 17–18; Jeff Foust, *Radio Telescope Faces "Extremely Concerning" Threat from Satellite Constellations*, SPACE NEWS (July 3, 2021), https://spacenews.com/radio-telescope-faces-extremely-concerning-threat-from-satellite-constellations/ [https://perma.cc/CH3B-CRP9] (archived Sept. 29, 2023) (noting technologies for identifying radio frequency interference by satellites and removing it from the observatory's data, which would cancel 4% of the observations); Stuart Eves, *Congested, Contested…Under Regulated and Unplanned*, ROOM (2021), https://room.eu.com/article/congested-contested-under-regulated-and-unplanned#:~:text=%2C%20contested...-,under%2Dregulated%20and%20unplanned, the%20order%20in%20the%20plot [https://perma.cc/C3U7-BJKP] (archived Sept. 29, 2023) (describing how terrestrial radio signals (such as from FM radio stations) can reflect off LEO satellites and be detected as interference by ground-based radio telescopes).

Telecommunication Union (ITU) allocates the available radio spectrum among prospective users.[85]

Less satisfying adjustments could include simply switching off either the radio telescope or the high-volume broadcasting satellite whenever an overflight occurs. Doing so would obviously interrupt either service temporarily, but there are not very many radio telescopes, and they are in remote locales.[86] Still, "some astronomical observations are unique and cannot be repeated at a later time as the sources fade or become more distant. Therefore, if such observations are corrupted by radio interference, the measurements they would have provided are lost forever."[87]

A satellite downlink that directly encounters a radio telescope can generate intolerable interference with the data collection, even saturating and blinding the receiver; at higher power levels, a mapping radar beam can burn out and damage or destroy the receiver.[88]

---

85. Brian Robinson, *Frequency Allocation: The First Forty Years*, 37 Ann. Rev. of Astronomy & Astrophysics (1999) (discussing the convoluted history of the allocation of frequencies to various competing users); Cavallaro, *supra* note 28 (explaining impact of satellite interference on the Square Kilometer Array observatory). *See* International Telecommunications Union Constitution art. 45 (requiring that "All stations, whatever their purpose, must be established and operated in such a manner as not to cause harmful interference to the radio services or communications of other Member States or of recognized operating agencies, or of other duly authorized operating agencies which carry on a radio service, and which operate in accordance with the provisions of the Radio Regulations."); ITU Radio Regulations art. 1.64 (defining a "space station" as "A station located on an object which is beyond, is intended to go beyond, or has been beyond, the major portion of the Earth's atmosphere.").

86. HANDBOOK, *supra* note 6, at 59 (noting that some phenomena of particular interest for radio astronomy are fleeting and non-repeating; others require simultaneous measurement from multiple instruments at different wavelengths and sites, so simply re-directing or temporarily turning off an observatory would be very disruptive); 2021 Report, *supra* note 25, at ¶ 35 (reporting that "no location on Earth was remote enough not to be affected by satellites"); LYALL & LARSEN, *supra* note 9, at 267, note 127 (recounting importance of ITU regulation requiring that satellites be capable of switching off their radio transmissions on command). Compounding the problem is the phenomenon of antenna "sidelobes." A radio astronomy antenna is inevitably sensitive to radiation that arrives from all directions, not solely where the main beam is oriented for peak response, and conversely, a transmitting antenna unavoidably radiates energy in directions away from its main beam. So simply "looking away" from a source of radio interference is not a completely successful solution. 2021 Workshop, *supra* note 2, at 272; 2021 CRP, *supra* note 6, at 16; Lawrence, Rawls, Jah, Boley, Vruno, Garrington, Kramer, Lawler, Lowenthal, McDowell & McCaughrean, *supra* note 19, at 431; U.S. GOV'T ACCOUNTABILITY OFF., *supra* note 51, at 32–34; Technology Assessment, *supra* note 10, at 32–34.

87. 2020 Workshop, *supra* note 3, at 171; Foust, *supra* note 81 (quoting astronomer Philip Diamond saying "What the megaconstellations do [to radio astronomy] is that they change the game for us.").

88. 2021 Workshop, *supra* note 2, at 272–73; 2020 Workshop, *supra* note 3, at 180; Lawrence, Rawls, Jah, Boley, Vruno, Garrington, Kramer, Lawler, Lowenthal, McDowell & McCaughrean, *supra* note 19, at 431; U.S. GOV'T ACCOUNTABILITY OFF., *supra* note 51, at 29 (describing danger to space-based observatories which might receive intense light reflections from other LEO satellites that could damage sensitive

Additionally, observers have recently discovered that most Starlink satellites' onboard electronics unintentionally "leak" electromagnetic radiation at wavelengths that are supposed to be protected for astronomy.[89] That is why radio telescopes need to be sited in remote, quiet areas, but no place is reliably isolated from mass satellite overflight, and the coming swarms of LEO satellites will be much harder to avoid than the smaller numbers of high-altitude orbiters that have been encountered to date. Experts conclude that this is "a time of unprecedented risk as the radio spectrum is exploited without adequate concern for the scientific enterprise."[90]

There have been some productive consultations between satellite operators, especially SpaceX,[91] and the astronomical community,

---

instruments); *The Megaconstellation Threat*, *supra* note 15, at 11 (describing potential damage to radio receivers); Cavallaro, *supra* note 28 (ruling out concerns about physical damage to receivers, but emphasizing saturation effects of interference, which can result in complete loss of data).

89. Michelle Starr, *SpaceX's Starlink Satellites Are Leaking Radiation, Scientists Confirm*, SCI. ALERT (July 10, 2023), https://www.sciencealert.com/spacexs-starlink-satellites-are-leaking-radiation-scientists-confirm [https://perma.cc/AX3V-UA9K] (archived Sept. 29, 2023); *New Radio Astronomical Observations Confirm Unintended Electromagnetic Radiation Emanating from Large Satellite Constellations*, INT'L ASTRONOMICAL UNION (July 5, 2023), https://cps.iau.org/news/new-radio-astronomical-observations-confirm-unintended-electromagnetic-radiation-emanating-from-large-satellite-constellations/#:~:text=Scientists%20use%20the%20LOFAR%20telescope,Further%20study%20is%20now%20ongoing [https://perma.cc/QYN9-54K9] (archived Sept. 29, 2023).

90. 2020 Workshop, *supra* note 3, at 181. *See also* JASON, *supra* note 10, at 4 (opining that "the current regulatory framework is insufficient to protect many modern radio astronomy observations"), 59 (concluding that "existing radio quiet zones are likely to be severely impacted" by satellite interference in the future); Cavallaro, *supra* note 28 (reporting that satellite interference with Square Kilometer Array observatory will require observations to take 70% longer; also asserting that available mitigations could reduce the impact by a factor of ten); Daniel Clery, *Starlink Already Threatens Optical Astronomy. Now, Radio Astronomers Are Worried*, SCI.SCIENCE (Oct. 9, 2020), https://www.science.org/content/article/starlink-already-threatens-optical-astronomy-now-radio-astronomers-are-worried [https://perma.cc/Y2R7-3PRX][] (archived Nov. 14, 2023); F. Di Vruno, *Unintended Electromagnetic Radiation from Starlink Satellites Detected with LOFAR between 110 and 188 MHz*, 676 Astronomy & Astrophysics 75 (Jul, 3, 2023) (reporting radio interference arising from the internal functioning of Starlink satellites, separate from the satellite's intentional emissions); Tereza Pultarova, *SpaceX's Starlink Internet Satellites "Leak" So Much Radiation That It's Hurting Radio Astronomy, Scientists Say*, SPACE (July 6, 2023), https://www.space.com/starlink-electronics-hum-disturbs-radio-astronomy [https://perma.cc/VDP4-8ZXT] (archived Sept. 29, 2023).

91. *Statement on Starlink and "Constellations" of Communications Satellites*, NAT'L RADIO ASTRONOMY OBSERVATORY (May 31, 2019), https://public.nrao.edu/news/nrao-statement-commsats/ [https://perma.cc/5YVC-GBEK] (archived Sept. 29, 2023) (reporting that discussions with SpaceX "have been fruitful and are providing valuable guidelines" and that "SpaceX has demonstrated their respect for our concerns and their support for astronomy"); White Paper, *supra* note 50, at 1 (SpaceX

attempting to reach mutually satisfactory accommodations. SpaceX has invested considerable engineering creativity and expense in experimental modifications to mitigate Starlink's reflectivity. But not all launching entities have participated in these exchanges, not all mitigation initiatives have been sufficient or sustained, and dialog alone cannot solve the problem. Although some might want to dismiss the interference problem as a mere "annoyance"[92] to be managed, others describe it as an "existential threat,"[93] and a more ominous warning was expressed by a 2020 working group of astronomical experts: "At present, the situation for astronomy is reaching a point of no return from continuous interference with observations and loss of science."[94]

---

says it has undertaken "deep, collaborative work" with the astronomy community to develop mitigations for satellite reflectivity); David Goldstein, SpaceX Satellites and the Night Sky, Presentation at Federation of Astronomical Societies' Webinar on Challenge of Megaconstellations (May 7, 2022), https://www.youtube.com/watch?v=MNc5yCYth5E [https://perma.cc/JQW2-NQNM] (archived Sept. 29, 2023) (describing SpaceX's multiple efforts at mitigating the impact of Starlink satellites); Maurizio Vanotti, Responsible Constellations, Presentation at Federation of Astronomical Societies' Webinar on Challenge of Megaconstellations (May 7, 2022), https://www.youtube.com/watch?v=MNc5yCYth5E [https://perma.cc/JQW2-NQNM] (archived Sept. 29, 2023) (discussing OneWeb's "Leadership in Responsible Space," including concerns about radio frequency interference and optical brightness); Jeff Foust, *Can Satellite Megaconstellations Be Responsible Users of Space?*, SPACE NEWS (Sept. 3, 2019), https://spacenews.com/can-satellite-megaconstellations-be-responsible-users-of-space/ [https://perma.cc/D576-55WU] (archived Sept. 29, 2023) (discussing OneWeb's "Responsible Space" initiative, which sees space as a shared natural resource, promising mindfulness of the company's potential effects on other users); *#Responsible Space: OneWeb's Commitment to Sustainability in Space*, ONEWEB, https://assets.oneweb.net/s3fs-public/assets/documents/OneWeb-Responsible-Space-Brochure.pdf?VersionId=tHc8CuB1W3JpVHulFaAKyqGiFqp1QcAs [https://perma.cc/J2BV-6PYN] (archived Sept. 29, 2023); SpaceX, Space Sustainability, May 7, 2022 (discussing SpaceX's collaboration with astronomers); Hofacker, *supra* note 42 (noting OneWeb's discussions with astronomers about interference); Witze, *supra* note 77 (reporting consultations and adaptations by OneWeb and Amazon, in addition to SpaceX); YOUNG & THADANI, *supra* note 39, at 20 (describing discussions between satellite companies and astronomers); Moro-Aguilar, *Potential Need*, *supra* note 43, at 497 (reporting contacts between astronomers and SpaceX, OneWeb, and Amazon regarding the problems of interference).

92. A.J. Mackenzie, *Who Speaks for the Night Sky?*, SPACE REV. (June 10, 2019), https://www.thespacereview.com/article/3728/1 [https://perma.cc/MRB8-LCRS] (archived Sept. 29, 2023) (arguing that the concerns about satellites' interference with astronomy are overstated).

93. Boyle, 2023, *supra* note 45 (quoting Harvard-Smithsonian astronomer Jonathan McDowell, regarding future dangers); *The Megaconstellation Threat*, *supra* note 15, at 3 (contending that the impact of satellite proliferation on optical and radio observatories has "the potential to end almost all professional ground-based astronomy over the next two decades").

94. 2020 Workshop, *supra* note 3, at 143; 2021 CRP, *supra* note 6, at 4 (concluding that "Without action from the international community, policymakers and industry, abundant LEO satellites will increasingly tarnish the pristine view of the natural night sky from our planet, and will increasingly imperil astronomical science."); Witze, *supra* note 77 (noting efforts by OneWeb and Amazon to experiment with techniques to reduce satellite brightness).

V. THE LAW

A. *The Outer Space Treaty*

Any international legal analysis in this field must begin with the Outer Space Treaty, the "Magna Carta" for space—although that document provides only incomplete and ambiguous guidance here.**[95]** This Section begins by highlighting several key provisions that establish important, but overlapping and partially contradictory, rights and responsibilities for states and other space-related actors.**[96]**

Article I of the OST introduces some of the most important overarching principles of space law. It provides that the exploration and use of outer space "shall be carried out for the benefit and in the interests of all countries"; that space "shall be free for exploration and use by all States"; that "[t]here shall be freedom of scientific investigation in outer space"; and that "States shall facilitate and encourage international cooperation in such investigation."**[97]** This lofty

---

95. LYALL & LARSEN, *supra* note 9, at 49–73 (addressing the importance and contents of the OST); STEPHEN HOBE, BERNHARD SCHMIDT-TEDD, KAI-UWE SCHROGL, COLOGNE COMMENT ON SPACE L., VOL. 1 (2019) (parsing the contents of the OST as the leading source of space law); Henry R. Hertzfeld, Brian Weeden,& Christopher D. Johnson, *How Simple Terms Mislead Us: The Pitfalls of Thinking about Outer Space as a Commons*, INT'L ASTRONAUTICAL FED'N (2015), https://swfound.org/media/205390/how-simple-terms-mislead-us-hertzfeld-johnson-weeden-iac-2015.pdf [https://perma.cc/85ZA-JEW6] (archived Sept. 29, 2023) (observing that commentators have expressed the view that key provisions of the OST are customary international law, binding even on states that have not joined the treaty) [hereinafter COLOGNE COMMENTARY]. *See also* U.N. Convention on International Liability for Damage Caused by Space Objects, Mar. 29, 1972, 24 U.S.T. 2389, 961 U.N.T.S. 187 [hereinafter Liability Convention or LIAB].

96. A treaty, including the OST, generally provides rights and obligations only for states, not for private actors, but the national undertakings may indirectly affect private parties. In addition, as discussed *infra*, text accompanying notes 105–07, the OST is highly unusual in requiring that a state is responsible for the space activities of its nationals and must authorize and continuously supervise those activities. 2021 Workshop, *supra* note 2, at 129–36.

97. OST, *supra* note 1, at art. I. The full text of that article provides: "The exploration and use of outer space, including the moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind. Outer space, including the moon and other celestial bodies, shall be free for exploration and use by all States without discrimination of any kind, on a basis of equality and in accordance with international law, and there shall be free access to all areas of celestial bodies. There shall be freedom of scientific investigation in outer space, including the moon and other celestial bodies, and States shall facilitate and encourage international co-operation in such investigation." *See* COLOGNE COMMENTARY, *supra* note 95, at 25–43; Giuliana Rotola & Andrew Williams, *Regulatory Context of Conflicting Uses of Outer Space: Astronomy and Satellite Constellations*, 46 AIR & SPACE L. 545, 555 (2021) (noting that the OST does not define key terms such as "exploration," "use," or "scientific investigation").

rhetoric supports the claims of both the satellite community and the astronomy community equally; neither has a basis for contending that it possesses inherently superior rights over the other.[98]

Article II provides that space "is not subject to national appropriation by claim of sovereignty, by means or use or occupation, or by any other means."[99] This means that no one can legitimately contend that "this segment of space is mine"—in other words, no State or private entity can reserve a portion of space for its exclusive or prioritized use.[100] Under well-settled State practice, satellite overflights of a country do not violate its sovereignty; unlike terrestrial or certain oceanic zones, space transit is unrestricted.[101]

Under Article III, parties agree to carry on their activities in the exploration and use of space "in accordance with international law . . . in the interest of maintaining international peace and security and promoting international co-operation and understanding."[102] Accordingly, international environmental law and international tort law, potentially including the law regarding "nuisance," as discussed *infra,* is applicable to space activities, and a premium is placed on developing cooperative, mutually-acceptable solutions, rather than one-sided dictates, for shared problems.[103]

---

98. Rotola & Williams, *supra* note 97, at 550 (emphasizing that the OST does not establish any priority or hierarchy among potentially competing uses of space); SATCON2, *supra* note 2, at 137–38 (calling for coordination mechanisms to resolve the conflict between different types of space activities indicated in art. I); Hertzfeld, *supra* note 95, at 3–5 (noting confusion over the definitions of key terms in OST art. I; emphasizing that both exploration and use of space are key principles in the OST). OST art. I does not promise that all states and other actors will derive equal benefits from space; it is best understood as ensuring equal, nondiscriminatory access to space and the opportunity to seek beneficial exploration and use. As the United States delegate commented during the negotiations, the language of art. I "make[s] clear the intent of the treaty that outer space and celestial bodies are open not just to the big powers or the first arrivals, but shall be available to all, both now and in the future." U.N. GAOR, 21st Sess., 1492d mtg. at 16, U.N. Doc. A/C.1/PV.1492 (Jan. 27, 1967).

99. OST, *supra* note 1, art. II. *See* COLOGNE COMMENTARY, *supra* note 95, at 44–63 (analyzing OST art. II).

100. *See* 2021 Workshop, *supra* note 2, at 107–10 (arguing that placing too many satellites into a particular LEO orbit may create such congestion that it effectively precludes others from using that orbital regime, thereby violating the non-appropriation principle, even if the state does not assert a formal, official claim to exclusive use); Johnson, *supra* note 36, at 15–21 (presenting a pro/con debate on whether large LEO satellite constellations constitute impermissible *de facto* appropriation); Byers and Boley, *supra* note 34, at 69–71.

101. COLOGNE COMMENTARY, *supra* note 95, at 27–28, 45 (noting the contrast between space law and air law regarding overflight rights).

102. OST, *supra* note 1, art. III; COLOGNE COMMENTARY, *supra* note 95, at 64–69 (analyzing OST art. III); 2021 Workshop, *supra* note 2, at 104–05 (discussing public international law and space law, noting that OST art. III is regarded as customary international law).

103. COLOGNE COMMENTARY, *supra* note 95, at 67 (asserting the applicability in space of international environmental law and the precautionary principle); Statute of the International Court of Justice, art. 38, ¶ 1 (identifying "general principles of law

Article VI of the OST creates an important, very unusual mechanism for international legal accountability for space activities. It provides that each state:

> Shall bear international responsibility for national activities in outer space . . . whether such activities are carried on by governmental agencies or by non-governmental entities, and for assuring that national activities are carried out in conformity with the provisions set forth in the present Treaty. The activities of non-governmental entities in outer space . . . shall require authorization and continuing supervision by the appropriate State Party.[104]

The activities of a private actor in space, such as a corporation that launches and operates satellites, are therefore attributable to the actor's state, and that state is responsible for monitoring and ensuring compliance with the rules.[105] The operations of SpaceX and its companions, therefore, are largely assimilated to and supervised by the various national governments under whose authority they operate.[106]

---

recognized by civilized nations" as one of the sources of international law that the court will apply).

104. OST, *supra* note 1, art. VI. *See* COLOGNE COMMENTARY, *supra* note 95, at 103–25 (analyzing OST art. VI).

105. It may be possible to argue that the OST reference to activities "in space" could exclude ground-based activity such as astronomy, but the better argument establishes a more capacious meaning for that phrase in the OST. Lawrence, Rawls, Jah, Boley, Vruno, Garrington, Kramer, Lawler, Lowenthal, McDowell & McCaughrean, *supra* note 19, at 429 (arguing that ground-based astronomy is an activity "in space"); COLOGNE COMMENTARY, *supra* note 95, at 34 (assessing that space activities include "production of satellite data in outer space or on Earth"), at 35 (arguing for a "rather wide approach" to defining "space activities"), at 107–09 (acknowledging the ambiguity about the meaning of an activity "in" space, and arguing in favor of a broad approach, to include activities that occur partly in space and partly on Earth); Rotola and Williams, *supra* note 97, at 555–61; 2021 Workshop, *supra* note 2, at 94–103, 116–17; Moro-Aguilar, *supra* note 65, at 6–7. *But see* Stefan Kirchner, The Impact of Large-Scale Satellite Constellations on Earth-based Astronomy as a Problem of International Law n. 15 (Jan. 12, 2020) (on file at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3518056 [https://perma.cc/TDY9-69HX]) (archived Sept. 29, 2023) (arguing that Earth-based astronomy is not covered by the OST rules about the freedom to conduct scientific investigation "in outer space"); 2021 Report, *supra* note 25, at ¶ 49 (reporting that "it was not clear whether States saw astronomy as a space activity"). In addition, it may be possible to differentiate here between a system like radar astronomy, which actively sends a signal into space and reads the reflection vs. a passive system like optical or radio astronomy, which exclusively receives signals generated by or reflected from a space object.

106. 2021 Workshop, *supra* note 2, at 110–14 (arguing that the responsibility to exercise "continuing supervision" should compel a state to regulate the ongoing activities of its satellite operators to achieve a balance with other space interests, including astronomy).

Article VII—as amplified by the 1972 Liability Convention—establishes a novel, complex tort liability regime that requires some careful parsing.[107] It specifies that a State responsible for a space object "is internationally liable for damage to another State Party to the Treaty or to its natural or juridical persons by such object or its component parts on the Earth, in air space or in outer space."[108]

Ordinarily, we would not anticipate that the competition in missions between an overflying spacecraft and an overflown observatory would inflict physical harm directly on either the satellite or the telescope.[109] Instead, the primary damage relevant here would be imposed on the observatory's work product—the imagery, charts, or other results that are marred by streaks of light or other indicia of interference. The Liability Convention defines "damage" as including "loss of or damage to property of States or of persons, natural or juridical."[110] It is now generally accepted that proprietary data can constitute valuable property,[111] so distortions inflicted on the observatory's acquired imagery by overflying satellites should be

---

107. OST, *supra* note 1, art. VII; LIAB, *supra* note 95 arts. II, III. A state whose space object causes damage to another state on Earth is "absolutely" liable; if the space object causes damage to another object in space, the state is responsible for "fault." In this Article, most of the attention is focused on damage inflicted on Earth (i.e., to ground-based observatories), but the operation of LEO satellite swarms also interferes with telescopes in orbit, so both types of liability may be invoked. To date, the treaty liability regime has been invoked only once, when a Russian satellite (Cosmos 954) crashed into northern Canada in 1978, spreading debris and requiring a substantial cleanup effort. Canadian Claim Against the Union of the Soviet Socialist Republics (USSR) for Damage Caused by Soviet COSMOS 954 ¶ 1, 1979, 18 I.L.M. 889; Protocol on Settlement of Canada's Claim for Damages Caused by COSMOS 954 arts. I–III, Apr. 2, 1981, 20 I.L.M. 689; LYALL & LARSEN, *supra* note 9, at 95–114,107 (discussing Cosmos 954). *See generally* COLOGNE COMMENTARY, *supra* note 95, at 126–45 (analyzing OST art. VII) and 83–226 (analyzing Liability Convention); BYERS & BOLEY, *supra* note 34, at 86.

108. OST, *supra* note 1, art. VII. This liability can attach jointly and severally to the state(s) that launch or procure the launching, or from whose territory or facility the space object is launched. LYALL & LARSEN, *supra* note 9, at 99–101; COLOGNE COMMENTARY, *supra* note 95, at 114–15.

109. HANDBOOK, *supra* note 6, at 18 (since most astronomy is purely passive, in receiving but not emitting signals, it does not cause interference with other users). *But see supra* note 66 (regarding use of laser adaptive optics, which might interfere with a satellite), and *supra* note 88 (regarding possible damage to sensitive radio telescope apparatus by very strong signals from spacecraft).

110. LIAB, *supra* note 95, art. I (a); COLOGNE COMMENTARY, *supra* note 95, at 141 (discussing the concept of damage under the OST), & 111–13 (damage under Liability Convention). Note that this definition of "damage" under the Liability Convention would not include environmental harm done to outer space itself.

111. Paulius Jurcys, Christopher Donewald, Mark Fenwick, Markus Lampien, Vytautas Nekrošius & Andrius Smaliukas, Ownership of User-Held Data: Why Property Law Is the Right Approach 5–7 (Sept. 21, 2021) (on file at https://jolt.law.harvard.edu/assets/digestImages/Paulius-Jurcys-Feb-19-article-PJ.pdf [https://perma.cc/9SLU-VNDZ]) (archived on Sept. 29, 2023); Jannice Kall, *The Materiality of Data as Property*, 61 HARV. INT'L L.J. 1, 1–2 (2020); Ivan Stepanov, *Introducing a Property Right over Data in the EU: The Data Producer's Right – An Evaluation*, 34 INT'L REV. L., COMPUTS. & TECH. 65, 65–66 (2020).

covered. To respond to the deleterious effects of the satellites, an observatory would have to dedicate additional time and money to altering its methods and equipment, or it would have to forego a portion of the sought data altogether.[112]

Note that the key provisions of the Liability Convention do not apply when the space object and the victim of damage inflicted by that space object are both from the same state.[113] In addition, note that the Liability Convention establishes a particular diplomatic mechanism for a state to present to another state a claim for compensation for damage suffered by the claimant's natural or juridical persons.[114] However, the treaty also specifies that it does not prevent those natural or juridical persons from independently pursuing a claim in the courts or administrative tribunals or agencies of the state that launched the allegedly offending space object.[115]

Finally, Article IX of the OST includes two other passages that might implicate the corresponding legal rights of the spacefaring and astronomical actors.[116] First, the treaty requires that "[i]n the

---

112. Barentine, Venkatesan, Heim, Lowenthal Kocifaj & Bará, *supra* note 63, at 253–54 (assessing monetary cost of satellite interference: $21.8 million annually for one observatory alone). *But see* Kirchner, *supra* note 105, at 4 (contending that "the factual loss of functionality [by astronomers] is unlikely to be considered a damage within the meaning of the Liability Convention…[u]nless human life or health is affected"). Also note one other possible interpretative question: OST art. VII provides liability for damage done by a space object "on the Earth." (The Liability Convention, *supra* note 95, art. II, says "on the surface of the Earth.") Does this language require that the space object itself must come to the surface of the Earth (as in a crash landing), or does it also cover a situation in which the space object remains in space but inflicts damage on Earth remotely, without a direct physical collision? The treaties are not explicit about this point, and there is no controlling state practice. However, the object and purpose of the treaties here were to ensure adequate protection for the victims of ultra-hazardous space activities, so the broader interpretation, embracing liability inflicted at any location, regardless of where the spacecraft was, should be preferred. *See* BYERS & BOLEY, *supra* note 34, at 86.

113. LIAB, *supra* note 95, at art. VII (a).

114. *Id.*, art. VIII. (specifying the use of diplomatic channels for presentation of the claim, imposing a one-year deadline, and contemplating the establishment of a Claims Commission to resolve lingering disputes.)

115. LIAB, *supra* note 95, at art. XI.2; *see also* Annie Handmer & Steven Freeland, *The Use of Law to Address Space Debris Mitigation and Remediation: Looking Through a Science and Technology Lens*, 87 J. AIR L. & COM. 375, 384 (2022) (observing that the Liability Convention is relevant only after a damaging event has occurred; it is not directly a preventative mechanism, apart from any deterrence value it might have).

116. Two other potentially relevant passages in OST art. IX are the obligations to avoid "harmful contamination" of space and to avoid "adverse changes in the environment of the Earth." It might be argued that the satellites' reflected light and active radio emissions constitute harmful contamination, but it is doubtful that this light and noise were part of what the treaty drafters had in mind as "contamination"; in addition, this part of the treaty obligation applies only to contamination of space and celestial bodies, not of Earth. Likewise, the art. IX obligation to avoid "backward

exploration and use of outer space . . . States Parties to the Treaty shall be guided by the principle of co-operation and mutual assistance and shall conduct all their activities in outer space . . . with due regard to the corresponding interests of all other States Parties to the Treaty."[117] The treaty does not define the pregnant concepts of "co-operation and mutual assistance" or "due regard," but they might well be invoked when the interests of the different communities collide.[118]

---

contamination" of Earth applies only to "the introduction of extraterrestrial matter" (i.e., not energy). *See* SATCON2, *supra* note 2, at 147–49); 2021 Workshop, *supra* note 2, at 109 (contending that "megaconstellations threaten megadebris," and OST art. IX warns against such irresponsible activities), 114–19 (construing art. IX).

117. OST, *supra* note 1, art. IX. *See* COLOGNE COMMENTARY, *supra* note 95, at 169–82 (analyzing OST art. IX).

118. *See* 2021 Workshop, *supra* note 2, at 115 (construing the key terms in OST art. IX); COLOGNE COMMENTARY, *supra* note 95, at 175–76 (discussing the concept of due regard); John Goehring, *The Russian ASAT Test Caps a Bad Year for the Due Regard Principle in Space,* JUST SEC. (Jan. 12, 2022) https://www.justsecurity.org/79820/the-russian-asat-test-caps-a-bad-year-for-the-due-regard-principle-in-space/ [https://perma.cc/GUR8-QCA3] (archived Sept. 29, 2023); Rotola & Williams, *supra* note 97, at 563 (discussing due regard as a limitation on the OST freedoms to explore and use space); Moro-Aguilar, *supra* note 65, at 3 (discussing the origins of the term "due regard" in aviation law, and concluding that under the OST, "Outer space is to be explored and used with due diligence, not only in accordance with one's own interests, but also taking into account the interests and rights of the remaining States Parties to the Treaty. The State must prove beyond a reasonable doubt that everything possible was undertaken to prevent a harmful act from occurring."); BYERS & BOLEY, *supra* note 34, at 105–09 (discussing the content of the concept of due regard); Jonelle John S. Domingo, U.N. Representative for the Republic of the Philippines, Statement to the United Nations General Assembly Open-Ended Working Group on Reducing Space Threats Through Norms, Rules and Principles of Responsible Behaviors (May 6, 2022) https://documents.unoda.org/wp-content/uploads/2022/05/PHILIPPINES-Statement-Under-Agenda-6-a.pdf [https://perma.cc/E4LF-3LET] (archived on Sept. 29, 2023) (asserting that "While the duty of "due regard" does not constitute a blanket limit on state conduct, it also does not permit states to merely note other states' rights and still do as they wish. Instead, its application depends upon the nature of the rights and duties involved, their importance, the extent of the anticipated impairment, the nature and importance of the activities contemplated, and the availability of alternative approaches."); Memorandum from the U.S. Secretary of Defense on Tenets of Responsible Behavior in Space (July 7, 2021) https://media.defense.gov/2021/Jul/23/2002809598/-1/-1/0/TENETS-OF-RESPONSIBLE-BEHAVIOR-IN-SPACE.PDF [https://perma.cc/6A3X-7DJJ] (archived on Sept. 23, 2023) (committing the U.S. military to "Operate in, from, to, and through space with due regard to others and in a professional manner."); Handmer & Freeland, *supra* note 115, at 383 (commenting that the requirement for "due regard" "imposes a restriction on unfettered exploration and use of outer space by requiring a due-diligence assessment of the potential impacts a particular activity may have on the activities undertaken by others.") In a different context, the Permanent Court of Arbitration has determined that the concept of due regard "does not impose a uniform obligation to avoid any impairment of [the second State's] rights; nor does it uniformly permit the [first State] to proceed as it wishes, merely noting such rights. Rather, the extent of the regard required by the Convention will depend upon the nature of the rights held by [the second State], their importance, the extent of the anticipated impairment, the nature and importance of the activities contemplated by the [first State], and the availability of alternative approaches." In the Matter of the South China Sea Arbitration (Phil. v. China), Case No. 2013-2019, Award,

Second, Article IX addresses the problem of "potentially harmful interference." It specifies that if a State

> [H]as reason to believe that an activity or experiment planned by it or its nationals in outer space . . . would cause potentially harmful interference with activities of other States Parties in the peaceful exploration and use of outer space . . . it shall undertake appropriate international consultations before proceeding with any such activity or experiment.**[119]**

On the flip side, a state that "has reason to believe that an activity or experiment planned by another State Party in outer space . . . would cause potentially harmful interference with activities in the peaceful exploration and use of outer space . . . may request consultation concerning the activity or experiment."**[120]**

Again, the OST does not define the key operative terms, such as "potentially harmful interference" and there is no affirmative state practice in invoking Article IX for these "consultations."**[121]** But it would be reasonable to contend that the high-visibility passage of reflective and radio-noisy satellites could constitute an "activity or experiment" in outer space that would cause "potentially harmful interference" with an overflown observatory's "activities in the peaceful exploration and

---

at ¶ 260 (Perm. Ct. Arb. 2016) (citing Chagos Marine Protected Area Arbitration (Mauritius v. U.K.), at ¶ 519 (Perm. Ct. Arb. 2015)) https://pcacases.com/web/sendAttach/2086 [https://perma.cc/8LHQ-P7YS] (archived on Sept. 29, 2023).

119. OST, *supra* note 1, art. IX. *See* Moro-Aguilar, *supra* note 65, at 2–4 (emphasizing the absence of definitions of key terms in the OST).

120. OST, *supra* note 1, art. IX. The OST does not define "interference," but ITU Radio Regulations define "harmful interference" as any "interference which endangers the functioning of a radionavigation service . . . or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with these [Radio] Regulations." Int'l Telecomm. Union [ITU], Reg. 1.169, *Harmful Interference, in* Radio Regulations Articles Edition of 2016, at 23 (2016). https://search.itu.int/history/HistoryDigitalCollectionDocLibrary/1.43.48.en.101.pdf [https://perma.cc/N26K-75CL] (archived on Sept. 23, 2023). Domestic U.S. law contains a parallel definition in 47 C.F.R. sec. 2.1(c). (Note that a telescope does not provide navigation or communications services.) Furthermore, "harmful interference occurs when the interference is deep and/or long enough to deteriorate the services of the affected systems." 2021 Workshop, *supra* note 2, at 115. *See* Moro-Aguilar, *supra* note 65, at 4–6 (discussing the origins of the art. IX consultation obligation).

121. Christopher J. Borgen, *Russia's ASAT Test and the Development of Space Law,* ARTS. WAR, (Nov. 21, 2021), https://lieber.westpoint.edu/russia-asat-test-development-space-law/ [https://perma.cc/F4CR-W2JU] (archived on Sept. 29, 2023); Goehring, *supra* note 118 (referring to the due regard principle as "toothless," and observing that states have not invoked OST art. IX in situations where it might have been useful); Moro-Aguilar, *supra* note 65, at 3 (arguing that the concept of harmful interference is broader under the OST than it is under the ITU Constitution).

use of outer space."[122] The treaty does not specify the nature or timing of any required consultations, or prescribe any particular outcome from them.

B. *General International Law*

Beyond the specifics of the OST, other sources of international law may be relevant in addressing the respective rights of satellite operators and observatories. The starting point, as usual, is the "freedom principle," enunciated by the Permanent Court of International Justice in the foundational 1927 *Lotus* case.[123] The key proposition there is simply that a sovereign state is basically free to do whatever it wants in international life, unless it has accepted a treaty or some other binding rule of international law that constrains its autonomy. In this light, unless the provisions of the OST or some other legal authority establish relevant restrictions, each state can freely place satellites into orbit (or authorize its nationals to do so), including in vast, sweeping armadas across the heavens. Reciprocally, each state is authorized to create, or to license and support, observatories of all manner. Crucially, however, general international law does not establish any automatic hierarchy among potentially contrary uses; there is, for example, no universal "first come, first served" principle according to which the original users of a resource can permanently reserve their privileged position.[124]

An alternative construct for international legal relations would be to insist upon some version of a "good neighbor" policy, under which each actor would be required to take into account the legitimate

122. As noted in OST *supra* note 1, art. IX, it could be argued that the term "activities in the peaceful exploration and use of outer space" should apply only to activities physically undertaken *in* outer space, excluding ground-based astronomy. *See*, however, the detailed analysis undertaken in 2021 Workshop, *supra* note 2, at 94–103, 116–17, concluding that ground-based astronomy "is or at least can be a form of space use and exploration," so the obligations and protections of OST art. IX do apply. *See also* Moro-Aguilar, *supra* note 65, at 2–3, 6–8 (discussing whether a terrestrial act such as ground-based astronomy can be a space activity); BYERS & BOLEY, *supra* note 34, at 99–104.

123. Case of the S.S. "Lotus" (Fr. v. Turk.), Judgement, 1927 P.C.I.J. (ser. A) No. 10, at 18 (Sept. 7) (ruling that "Restrictions upon the independence of States cannot therefore be presumed"). *See* Peter Hulsroj, *Three Sources – No River*, 54 AUSTRIAN J. PUB. & INT'L L. 219, 219 (2009) (criticizing the freedom principle as the basis for international law).

124. SATCON2, *supra* note 2, at 125, 144–45 (contrasting the application of a *de facto* "first come, first served" allocation system for satellite operations in LEO, compared to ITU rules that mostly establish more orderly international mechanisms to apportion access to geosynchronous orbital slots and associated radio frequencies, and calling for a process to ensure more equitable use of LEO); Johnson, *supra* note 36, at 11 (noting how the ITU attempts to employ both a "first come, first served" principle and some protection for future users, regarding geostationary orbital slots and frequencies); Hope Babcock, *The Public Trust Doctrine, Outer Space, and the Global Commons: Time to Call Home ET*, 69 SYRACUSE L. REV. 191, 227–29 (2019) (critiquing the rule of first possession).

interests of other states, and would be obliged, in good faith, to try to accommodate other reasonable stakeholders.[125] Some provisions of OST Article IX may constitute an endorsement of that direction (e.g., invoking the "principle of co-operation and mutual assistance"; the concept of exhibiting "due regard" for the interests of others; and promoting the avoidance of "potentially harmful interference"), but these are hardly a comprehensive or specific mandate to extend full consideration or to defer automatically to other space users.[126]

International environmental law may also suggest a useful supplement here.[127] The famous Trail Smelter Case,[128] a 1941 arbitration between the United States and Canada, establishes the principle that no state has the right to use or permit the use of its territory in such a manner as to cause serious injury (in that litigation, via the emission of noxious sulphur dioxide fumes) to the territory, population, or property of another state. Although outer space is decidedly not within the "territory" of any state, and a satellite's reflected light or radio waves are quite different in nature from particulate air pollution, one might argue by extension that the underlying principle could be enlisted to protect ground-based or space-based astronomy.[129] The International Court of Justice has further entrenched this proposition, concluding that "the general obligation of States to ensure that activities within their jurisdiction and control respect the environment of other States or of areas beyond national

---

125. Peter Hulsroj, *To the Rescue, All Hands!: The Good Neighbor Principle in International Law*, 1 IRISH Y.B. INT'L L. 167, 178–184 (2006); Kirchner, *supra* note 105, at 2 (commenting on the principle that one who profits from the use of a global resource should share the benefits with all mankind); I.L.C., *infra* note 127, arts. 8–10 (calling for notification and consultation among states if there is a risk of an activity resulting in significant transboundary harm, and the states "shall seek solutions based on an equitable balance of interests," art. 9.2); 2021 Workshop, *supra* note 2, at 105.

126. COLOGNE COMMENTARY, *supra* note 95, at 175–76 (discussing concepts of due regard and corresponding interests, suggesting "States should avoid any measures aimed at hampering the space activities of other States" and saying that due regard "is indeed a qualification of the rights of States in exercising the freedoms in outer space" and "The State must prove beyond a reasonable doubt that everything possible was undertaken to prevent a harmful act from occurring.") The concept of due regard is also used (again, without definition or other elaboration) in the 1982 U.N. Convention on the Law of the Sea, 1833 U.N.T.S. 3, 21 I.L.M. 1261, arts. 56.2, 58.3. *See also* the 1986 Principles Relating to Remote Sensing of the Earth from Outer Space, adopted by the U.N. General Assembly on December 3, 1986, G.A. Res. 41/65, at Principle IV (Dec. 3, 1986) asserting that remote sensing "shall not be conducted in a manner detrimental to the legitimate rights and interests of the sensed State".

127. 2021 Workshop, *supra* note 2, at 122–24 (discussing the general applicability of environmental law to space); LYALL & LARSEN, *supra* note 9, at 245–80; COLOGNE COMMENTARY, *supra* note 95, at 176–79.

128. Trail Smelter Case (U.S. v. Can.), 3 Arb. Trib., 1905 (1950).

129. SATCON2, *supra* note 2, at 127–28, 168–71 (arguing that a state has a legal responsibility to prevent transboundary environmental harm, and that the OST makes a state liable for the damage in space created by its nationals.)

control is now part of the corpus of international law relating to the environment."[130]

The "soft law" of the environment and of space reinforces that perspective.[131] The 1992 Rio Declaration from the UN Earth Summit includes key universal principles declaring that states have "the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction" and that "[t]he right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations."[132] The 2019 UN Guidelines for the Long-Term Sustainability of Outer Space Activities include, *inter alia*, a commitment to "[p]romote regulations and policies that support the idea of minimizing the impacts of human activities on Earth as well as on the outer space environment."[133] The International Law Commission has determined that there is an obligation for a state to "take all appropriate measures to prevent significant transboundary harm" and that states "shall cooperate in good faith" toward that end.[134] In like manner, the 2020 US National Space Policy includes a provision "recognizing the importance of

---

130. Legality of the Threat or Use of Nuclear Weapons, Advisory Opinion, 1996 I.C.J. Rep 226, ¶ 29.

131. The term "soft law" includes a variety of norms, principles, and practices that have not crystalized into legally binding form but that carry such great social utility and practical weight that they do influence behaviors. *See* SOFT LAW IN OUTER SPACE: THE FUNCTION OF NON-BINDING NORMS IN INTERNATIONAL SPACE LAW, (Irmgard Marboe ed., 2012); LYALL & LARSEN, *supra* note 9, at 45–48 (discussing soft law of space). *See also* the "precautionary principle," obligating states and other actors to exercise care in making decisions that may affect the environment, even if the data necessary for a complete analysis of the potential damage is not yet available. As presented by the Rep. of the Secretary General on Gaps in International Environmental Law and Environment-related Instruments: Towards a Global Pact for the Environment, U.N. Doc. A/73/419 at 8 (2018), "This principle stipulates that States are required to adopt a precautionary approach when taking decisions or in regard to potential omissions which may harm the environment. Such a duty remains intact irrespective of the absence of scientific certainty as to the existence or extent of such risk." SATCON2, *supra* note 2, at 175–78; COLOGNE COMMENTARY, *supra* note 95, at 67 (supporting the applicability of the precautionary principle in space); Paul B. Larsen, *Application of the Precautionary Principle to the Moon*, 86 J. AIR L. & COM., 3 (2006).

132. Rep. of the U.N. Conference on Environment and Development, U.N. Doc. A/CONF.151/26 at 1–2 (1992); Rep. of the U.N. Conference on the Human Environment, U.N. Doc. A/CONF.48/14 at 5. *See also* Moro-Aguilar, *supra* note 65, at 8.

133. U.N. Comm. on the Peaceful Uses of Outer Space, Guidelines for the Long-Term Sustainability of Outer Space Activities (Jan. 2019) at 9; SATCON2, *supra* note 2, at 165–67.

134. Rep. on Int'l L. Comm'n, Draft Articles on Prevention of Transboundary Harm from Hazardous Activities with Commentaries, U.N. Doc. A/56/10 (2008), at arts. 3–4. These obligations can apply to activities undertaken in, or with effects in, outer space. *See also* 2021 Workshop, *supra* note 2, at 124–25 (discussing application of environmental law principles); Rep. on Int'l L. Comm'n , Draft Articles on Responsibility of States for Internationally Wrongful Acts, with Commentaries, U.N. Doc. A/56/10 (2001), at Chapter I (establishing principles for state responsibility).

preserving the space environment to enhance the long-term sustainability of space activities."[135]

C. *The Law of Nuisance*

Another potentially fruitful source of legal analogy, originating far from the realm of outer space, would be the common law of private nuisance, which finds expression in many national legal systems. This longstanding branch of tort and property law operates to protect the right to innocent enjoyment of real property by interdicting neighbors who generate excessive, offensive noises, lights, odors, pollution, or other disruptive phenomena.[136]

A landowner (or occupier), such as an observatory, is not legally protected against every nontrespassory intrusion; typically, the offense must be both substantial and unreasonable in imposing an unacceptable burden. Sometimes, the key tests undertake to weigh the gravity, duration, and type of harm suffered; the social utility of the respective parties' conduct; and the burden and benefit for each side of avoiding or remediating the harm, among other values.[137]

If applied to the predicament of astronomers and satellite operators, these principles could validate a private right of action, claiming that the radio noise and reflected sunlight from overflying spacecraft interfere unacceptably with observatories' routine operations, compromising their functions and mangling their data. Proper remedies could include monetary damages or injunctive relief, recognizing the fact that while both participants (the astronomers and the satellite companies) are performing legitimate, socially valuable

---

135. NATIONAL SPACE POLICY OF THE UNITED STATES OF AMERICA (2020), at 14. *See also* NEW MILLENNIUM, *supra* note 4, at 196–97 (assessing current and emerging environmental impacts on astronomical observations and asserting that deteriorating conditions mean that many planned astronomy programs "may never reach their full potential").

136. *See generally*, JOSEPH WILLIAM SINGER, PROPERTY 99–139 (4th ed. 2014) (collecting cases litigating claims about excessive light and noise, *inter alia*); RESTATEMENT OF TORTS (SECOND) § 821–31 (AM. L. INST. 1979); SOPHIE STIJINS & ROGER BLANPAIN, INTERNATIONAL ENCYCLOPAEDIA OF LAWS: TORT LAW (2002); WILLEM H. VAN BOOM, MEINHARD LUKAS & CHRISTA KISSLING, TORT AND REGULATORY LAW 419–449 (2007).

137. Singer, *supra* note 136 at 106–09; Restatement, *supra* note 136, sec. 827–28 (observing, at p. 112, that "It is an obvious truth that each individual in a community must put up with a certain amount of annoyance, inconvenience and interference and must take a certain amount of risk in order that all may get on together. The very existence of organized society depends upon the principle of "give and take, live and let live," and therefore the law of torts does not attempt to impose liability or shift the loss in every case in which one person's conduct has some detrimental effect on another. Liability for damages is imposed in those cases in which the harm or risk to one is greater than he ought to be required to bear under the circumstances, at least without compensation.")

functions, it cannot be assumed that the adverse external consequences of their overlapping needs should be allowed to rest perpetually wherever they initially happen to fall.[138]

Notably, the question of the offensiveness of an intrusion is typically assessed by the standard of a hypothetical reasonable person; someone or some activity that is hypersensitive may not be well protected against a nuisance that would not trouble others. On the other hand, even a very sensitive plaintiff has a right to live and work somewhere. So an optical or radio observatory would face a challenge in asserting a traditional claim about types of interference that would hardly be noticed by other landowners.[139]

Chronological priority in use is not decisive here; the concept of "coming to the nuisance" does not preclude recovery by an actor who moves into a jeopardized situation, already knowing about the potential annoyance, but it is a relevant factor in assessing reasonableness and damages.[140] In the case of astronomy, many of the most impacted observatories were in place or under construction long before Starlink and its companions began to appear, and they were deliberately ensconced in out-of-the-way sites, precisely to avoid interference. But when as many as 100,000 LEO satellites may soon appear overhead, there is no location sufficiently remote to avoid the nuisance.[141]

D. *Global Commons*

Is outer space a "global commons"? If so, how might that status affect the legal analysis of the respective rights and restraints on states and non-state actors in the realm? It is beyond the scope of this Article to recapitulate the longstanding, vigorous debate about space as a

---

138. Singer, *supra* note 136, at 104–06, 111–20; Restatement, *supra* note 136, sec 822, comment d. Note that local zoning laws or licenses (such as the satellite operators' authorizations from the FCC) may alter the standard allocation of rights. *Id.* at 102. The paradigmatic nuisance case involves neighboring landowners, but the concept extends more broadly: the plaintiff need not be the owner of the affected property, as long as it is a legitimate occupant or user; and the defendant need not be an adjacent landowner, but could be a moveable source of intrusion, such as the operator of an aerial drone. *See* Hillary B. Farber, *Keep Out: The Efficacy of Trespass, Nuisance and Privacy Torts as Applied to Drones*, 33 GA. ST. U. L. REV. 359, 406–409 (2017); Vivek Sehrawat, *Liability Issue of Domestic Drones*, 35 SANTA CLARA HIGH-TECH. L.J. 110, 130–134 (2018).

139. Restatement, *supra* note 136, sec. 821F, comment d; Singer, *supra* note 136 at 107 (emphasizing that for a nuisance claim to prevail, it is not the defendant's conduct that must be judged unreasonable; it is the effect on the plaintiff that must be unreasonable).

140. Singer, *supra* note 136 at 123–24.

141. Note also the difficulty in assigning responsibility to any particular satellite or operator, when there are so many constellations operating simultaneously. To some extent, it is the cumulative effect, rather than any particular orbiter, that damages astronomy. Still, some actors, such as Starlink, are so large that their predominant effect can be assessed independently, and it would ordinarily be possible to identify a particular satellite that had caused a particular streak on an observatory's imagery.

commons—the literature abounds with resolutely contrasting views.[142] But it is possible at least to identify three salient features of the space domain that are cognate to the general concept of a commons and that should strongly influence the allocation of responsibilities between astronomers and satellite operators.

First, there is a grave danger of over-use of the resource, leading to a "tragedy of the commons" to the detriment of all.[143] As tens of thousands of new satellites (and the associated mission debris) are

---

142. COLOGNE COMMENTARY, *supra* note 95, vol. 1, at 27–29 (comparing space to other common areas); SATCON2, *supra* note 2, at 75 (asserting that space is a global commons); U.N. Secretary-General, *Our Common Agenda,* 17–18, 48, U.N. Doc. A/75/982 (2021) (listing outer space, along with the high seas, the atmosphere, and Antarctica, as global commons, and calling for improved protection of them); Hertzfeld, *supra* note 95, at 2–3 (noting that the term "commons" does not appear in any space related treaties, but is frequently applied by governmental and other commentators in discussing space), at 5–6 (arguing that space does not fit the historical concept of a commons); Daniel Patton, *Is Space a Global Commons?* Secure World Foundation Space Sustainability Brief, 2 (2022), https://swfound.org/media/207517/swf_brief_is_space_a_global_commons_pp2301_final.pdf [https://perma.cc/7D6B-2FH3] (archived Sept. 23, 2023), (quoting contradictory U.S. government statements about whether space is a global commons); Exec. Order No. 13914, 85 Fed. Reg. 20,381 (Apr. 10, 2020) ("the United States does not view [outer space] as a global commons."); Scott Pace, Space Development, Law, and Values, Galloway Space Law Symposium, (Dec. 13, 2017) (asserting that space is not a global commons and the United States has consistently taken the position that the legal status of space should not be described by that legal construct); GLOBAL COMMONS: THREAT OR OPPORTUNITY? FINMECCANICA OCCASIONAL PAPER (Claudio Catalano ed., 2013) (discussing outer space, along with air, sea, and cyberspace as global commons); John S. Goehring, *Why Isn't Outer Space a Global Commons?* 11 J. NAT'L SEC. L. & POL'Y 573, 574–577 (2021); Aaron C. Boley & Michael Byers, *Satellite Mega-constellations Create Risks in Low Earth Orbit, the Atmosphere and on Earth*, NATURE SCI. REPS., May 20, 2021, at 1, 5, https://www.nature.com/articles/s41598-021-89909-7 [https://perma.cc/KTH8-X8YC] (archived Sept. 23, 2023); Babcock, *supra* note 124.

143. Garrett Hardin, *The Tragedy of the Commons*, 162 SCI. 1243, 1243–1245 (1968) (describing the persistent problem of over-use of a shared resource, to the common detriment); Lawrence, Rawls, Jah, Boley, Vruno, Garrington, Kramer, Lawler, Lowenthal, McDowell & McCaughrean, *supra* note 19, at 430 (arguing that the "orbital carrying capacity" of particular space "highways" is likely to become saturated by excessive use, making them "useless for the safe conduct of space operations and activities"); Nancy Gallagher, *Space Governance and International Cooperation*, 8 ASTROPOLITICS, 256, 259 (2010); BOLEY & BYERS, *supra* note 135 (contending that competition in space "risks multiple tragedies of the commons"); Miles Lifson & Richard Linares, *Is There Enough Room in Space for Tens of Billions of Satellites, as Elon Musk Suggests? We Don't Think So*, SPACE NEWS (Jan. 4, 2022) https://spacenews.com/op-ed-is-there-enough-room-in-space-for-tens-of-billions-of-satellites-as-elon-musk-suggests-we-dont-think-so/ [https://perma.cc/FPJ3-UZKN] (archived Sept. 23, 2023) (stressing that "Space is a communal and *finite* resource – for better or for worse, when one nation uses it, it limits the orbits that can be used by others." (emphasis in the original).). Note that the definition of "damage" under the Liability Convention includes harm done to property of states, international intergovernmental organizations, and natural or juridical persons, but not damage done to space itself as a global commons. LIAB, *supra* note 95, art. I(a).

catapulted into LEO, the dangers of congestion, collisions, and interference will soar accordingly. Each country and each corporation will have only limited incentive to husband the profitable orbital swaths, and even less reason to attend to the interests of other stakeholders, such as ground- and space-based astronomers interested in peering past the orbiting cloud.

Second, pursuant to the lack of effective global regulation, each state experiences incentives to be permissive or even aggressive in sponsoring new constellations of spacecraft. As states perceive benefits in attracting and facilitating ambitious space actors, there can be a regulatory "race to the bottom" and a more general "space race" to be the first to exploit the opportunities, regardless of the imposition of externality costs on others.[144]

Finally, these dynamics will inexorably tilt the system in favor of the pursuit of short-term payoffs, at the cost of underinvesting in long-term benefits. Communications satellites, for example, will provide immediate improvements in internet service, as well as enormous financial gains for the providers. In contrast, the value of space science may seem remote and speculative, and the opportunity cost of foregone (or delayed or impeded) discoveries may seem distinctly secondary.

In sum, the deficit in global governance of space, whether or not the domain is formally characterized as a global commons, will impede cooperative international steps to mediate the fracas between satellites and telescopes. No country, acting alone, can achieve a satisfactory global resolution of the competing interests, and each country, in sovereign pursuit of national advantage, may make the situation worse. The shards of international law—declaring that space is free for

144. *See* Pace, *supra* note 142 (arguing that "the United States should strive to be the most attractive jurisdiction in the world for private sector investment and innovation in outer space. This requires a transparent, efficient, and minimally burdensome domestic regulatory mechanism."); Jeff Foust, *Japan Passes Space Resources Law*, SPACE NEWS (June 17, 2021), https://spacenews.com/japan-passes-space-resources-law/ [https://perma.cc/LRL7-7WZK] (archived Sept. 23, 2023) (reporting adoption by Japan of legislation authorizing mining of space resources, comparable to enactments in United States, Luxembourg, and United Arab Emirates, while other countries, including Russia and New Zealand favor international regulation instead); U.S. Commercial Space Launch Competitiveness Act, Pub. L. No. 114-90, Chapter IV, (2015) (US legislation granting corporations the right to acquire minerals from space, notwithstanding OST art. II prohibiting national appropriation); Thomas Taverney, *Proliferated LEO Is Risky But Necessary*, SPACE NEWS (Mar. 5, 2020), https://spacenews.com/op-ed-proliferated-leo-is-risky-but-necessary/ [https://perma.cc/VG2K-F7DS] (archived Sept. 23, 2023) (characterizing a "gold rush" in LEO, with commercial satellite ventures "vying to be the first and build the most in order to drive competitors out of the marketplace"); OLSON, BUTOW, FELT & COOLEY, *supra* note 46 (exhorting the United States to engage more vigorously in a new space race with China); Hoss Cartwright & Deborah Lee James, *The Space Rush: New US Strategy Must Bring Order, Regulation*, DEFENSE NEWS (Mar. 26, 2021), https://breakingdefense.com/2021/03/the-space-rush-new-us-strategy-must-bring-order-regulation/ [https://perma.cc/X48G-2SGN] (archived Sept. 23, 2023) (calling for U.S. leadership in establishing a stable rules-based order to regulate national and private activities in space).

exploration and use by all, that it is not subject to sovereign appropriation, and that each user must demonstrate due regard for the interests of others[145]—may seem like weak reeds when challenged by the imperatives of the search for commercial advantage.

VI. RECONCILIATION

There are several plausible approaches toward mitigating the antagonisms between satellite operators and astronomers—unfortunately, the ideas that would be relatively cheap and easy are unlikely to be very effective and enforceable, and the ideas that would be most effective and enforceable are unlikely to be cheap and easy.[146]

A. *Adjustments by the Satellite Operators*

The first category of responses includes moves that could be undertaken by the space companies and their governments; for purposes of comprehensiveness, it includes some options that would be logically available but financially or politically quite unattractive.[147]

Limit the number of satellites. The most obvious way to mitigate the damage imposed by overflying satellites would be to cap (and reduce) the quantity of such spacecraft. For equally obvious reasons, this proposal would be a non-starter for many people.[148]

---

145. *See supra* notes 97-122 and accompanying text.

146. SATCON1, *supra* note 6, at 16–22 (recommendations for satellite operators and observatories); 2021 Workshop, *supra* note 2, at 82–84 (collecting and organizing several technical, policy, and legal recommendations); 2021 Working Paper, *supra* note 31, at 3–4; 2021 Report, *supra* note 25, at ¶¶ 59–60; U.S. GOV'T ACCOUNTABILITY OFF., *supra* note 10, at 26–28, 35-36 (presenting options for mitigating the effects of LEO satellites on optical and radio observatories); Technology Assessment, *supra* note 10, at 26–28.

147. SATCON1, *supra* note 6, at 49; HANDBOOK, *supra* note 6, at 107–13 (concluding that no single technique can prevent or repair all the harm done by interference to radio astronomy, so several layers of mitigation will be required); Hecht, *supra* note 52, at 30–34 (identifying various mitigations available for different types of satellites); *A Report on the Impact of Satellite Constellations*, EUR. ORG. FOR ASTRONOMICAL RSCH. IN THE S. HEMISPHERE (Nov. 16, 2020), https://arxiv.org/ftp/arxiv/papers/2108/2108.03999.pdf [https://perma.cc/FM9X-H9DG] (archived Sept. 23, 2023).

148. 2020 Workshop, *supra* note 3, at 135; SATCON2, *supra* note 2, at 77 (calling for halting or slowing the pace of launches for satellite constellations); Falchi, *supra* note 21 (calling for a strategy to cap the number of satellites, and considering prohibiting megaconstellations); SATCON1, *supra* note 6, at 5; Lawrence, Rawls, Jah, Boley, Vruno, Garrington, Kramer, Lawler, Lowenthal, McDowell & McCaughrean, *supra* note 19, at 432 (concluding that launching significantly fewer satellites is the only mitigation technique that could fully avoid harm to astronomical science); FCC 2021 Order, *supra* note 55, at 49 (noting that Viasat has argued that the best way to mitigate the light

Limit the orbital altitudes at which the satellites fly. A constellation circling below about 600 kilometers is generally less damaging to ground- and space-based observatories than those flying higher. In this respect, the configuration of OneWeb (at 1200 kilometers) is much worse than that of Starlink (at 550 kilometers).[149]

Some authorities suggest that clumping the satellites into co-flying clusters, instead of spreading them out evenly across the skies, would be advantageous, making it easier for observatories to point their telescopes away from the offending glare.[150] However, this approach would compromise the satellite operators' goals of continuous global coverage.

SpaceX has generally adopted a practice of initially placing new satellites in a very low orbit, holding them there for a few days or weeks to ensure they are all operational, before adjusting their orbits to the higher, final altitude. This initial stage creates some of the brightest and most obnoxious interference and could be avoided by altering the launch routine.[151]

Tweak the satellite design, to reflect less sunlight and emit less radio noise. Several different types of adaptations may be available here. For example, SpaceX briefly experimented with reducing the albedo (reflectivity or brightness) of some Starlink satellites by darkening their exterior color or attaching a visor or hood. It would also be possible to alter the alignment of the spacecraft so that the largest reflective surfaces were positioned to avoid or dim the reflection of solar light toward Earth, especially at twilight and dawn. At a more radical level, the space companies could undertake a thorough re-design of the satellites, adopting a conscious goal of minimizing harm to optical and radio telescopes, perhaps by employing

---

pollution effects of the Starlink constellation is to place fewer satellites in low-Earth orbit); Barentine, Venkatesan, Heim, Lowenthal, Kocifaj & Bará, *supra* note 63, at 256 (suggesting greater reliance upon fiber optic cables and improved terrestrial wireless data networks instead of satellites).

149. 2020 Workshop, *supra* note 3, at 135–36; JASON, *supra* note 10, at 40 (recommending requiring OneWeb to operate only at altitudes below 600 kilometers and discouraging other large constellations higher than that level); Bassa, Hainaut & Galadi-Enriquez, *supra* note 44, at 14 (calculating that a constellation orbiting at 1000 kilometers altitude will be more damaging than a three times larger constellation at 500 kilometers); Hecht, *supra* note 52, at 32 (quoting astronomer Jonathan McDowell saying "Starlinks are really annoying but manageable. OneWeb is 'Pack up your telescope and go home.'") *But see* Foust, *Satellite*, *supra* note 91 (observing that there are fewer satellites and less debris at 1200 kilometers altitude, lessening the dangers). A majority of the Starlink Generation 2 satellites will orbit as low as 340-360 kilometers; it is not yet known what effect such a low flight path will have on light reflections toward Earth. FCC 2022 Order, *supra* note 30, at 7–8. Notably, a constellation operating at a lower altitude will require more satellites in order to achieve comparably global coverage.

150. 2020 Workshop, *supra* note 3, at 148–49; SATCON1, *supra* note 6, at 6.

151. FCC 2021 Order, *supra* note 55, at 36 (noting that this launch practice also facilitates the prompt de-orbit of satellites that fail to operate properly after initial deployment, reducing the dangers of prolonged debris); FCC 2022 Order, *supra* note 30, at 46.

some of the low-observable "stealth" technology that already characterizes "black" military and intelligence spacecraft. At a more fundamental level, the satellite designers could engage with representatives of the astronomy community early in the design and construction process, soliciting their input and providing plenty of advance notice about, and testing of, new features, and providing time for observatories to advise and adapt.[152] Likewise for unwanted interference from radio emanations, improved satellite design and deferential operations might help mitigate the worst problems.[153]

Restrain some satellite operations. Satellite companies could establish a capacity (and demonstrate a willingness) to temporarily move, twist, or silence a satellite to enable particularly time-sensitive

152. 2020 Workshop, *supra* note 3, at 136; JASON, *supra* note 10, at 41; SATCON1, *supra* note 6, at 53–54; Jeff Foust, *Little Legal Recourse for Astronomers Concerned About Starlink*, SPACE NEWS (Jun. 3, 2019), https://spacenews.com/little-legal-recourse-for-astronomers-concerned-about-starlink/ [https://perma.cc/BF8F-HRCQ] (archived Sepr. 25, 2023) (quoting Elon Musk as being interested in reducing the albedo of Starlink satellites, and tweeting "If we need to tweak sat orientation to minimize solar reflection during critical astronomical experiments, that's easily done."); FCC 2021 Order, *supra* note 55, at 48–49 (observing that SpaceX has undertaken efforts to mitigate the deleterious effect on astronomy of the Starlink constellation); FCC 2022 Order, *supra* note 30, at 47–52; Tyson, *supra* note 60, at 2 (identifying the "key goal" of decreasing the brightness of satellites, via darkening or shading their reflective surfaces to reduce light flares); Barentine, Venkatesan, Heim, Lowenthal, Kocifaj & Bará, *supra* note 63, at 256 (critiquing efforts to mitigate satellite brightness); Moro-Aguilar, *Potential Need*, *supra* note 43, at 497–98; Leonard David, *Anatomy of a Spy Satellite*, SPACE.COM (Jan. 3, 2005), https://www.space.com/637-anatomy-spy-satellite.html [https://perma.cc/S6K6-BQUR] (archived Sept. 25, 2023); Stephen Chen, *Chinese Researchers Look at How to Keep Satellites Under the Radar*, SOUTH CHINA MORNING POST (July 29, 2021), https://www.scmp.com/news/china/science/article/3142902/chinese-researchers-look-how-keep-satellites-under-radar [https://perma.cc/Y8E3-XLAG] (archived Sept. 25, 2023); Seitzer & Tyson, *supra* note 59 (urging satellite builders to incorporate a "design to be faint" principle into the early phases of their work). The serial adaptations in Starlink designs – from the original model to generation 1.5 and now to generation 2.0 – could have provided opportunities for more in-depth consultations with astronomers, to vet the new configurations and allow input and testing regarding reflectivity effects. *See* Eric Ralph, *SpaceX's First Starlink V2 Satellites Spotted at Starbase,* TESLARATI (Jul. 20, 2022), https://www.teslarati.com/spacex-starlink-v2-satellites-spotted-starbase/ [https://perma.cc/YKD2-9N72] (archived Sepr. 25, 2023); Eric Ralph, *SpaceX CEO Elon Musk Reveals Next-Generation Starlink Satellite Details*, TESLARATI (May 30, 2022), https://www.teslarati.com/spacex-elon-musk-next-gen-starlink-satellite-details/ [https://perma.cc/3GSJ-UUQM] (archived Aept. 25, 2023); Evelyn Janeidy Arevalo, *SpaceX Depends on Starship's Success to Launch the Next-Generation Starlink 2.0 Satellites Says Elon Musk*, TESMANIAN (Jun. 4, 2022) https://www.tesmanian.com/blogs/tesmanian-blog/starlink-2-0 [https://perma.cc/7X4C-LEN7] (archived Sept. 25, 2023). More broadly, *see International Astronomical Union Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference*, INDUSTRY & TECHNOLOGY HUB, https://cps.iau.org/industry-and-technology-hub/ [https://perma.cc/9PVQ-UCAV] (archived Sept. 25, 2023) (describing outreach and engagement between astronomers and satellite operators).

153. Technology Assessment, *supra* note 10, at 35–36.

astronomical observations to proceed; they could prioritize the collection of critical scientific data during these temporary interruptions in normal satellite services.[154]

Provide more timely and detailed advance information about satellite locations and orbits. If the observatories know more about when and where the interference will arise, they can adapt better, anticipating where the damaging points of light will be, and planning to avoid them to the extent possible.[155]

Regarding radio astronomy in particular, turn off or deflect the satellite transmitter when overflying an observatory's quiet zone. More broadly, support enlightened spectrum management practices to better protect the frequencies and the quiet zones dedicated to observatories.[156]

---

154. 2020 Workshop, *supra* note 3, at 147 (describing particular applications for which the immediate collection of astronomical data is urgent); SATCON1, *supra* note 6, at 60; Tyson, *supra* note 60, at 11 (describing SpaceX's operational mitigation of "rolling" the satellite edge-on to the sun, to reduce reflections.)

155. 2020 Workshop, *supra* note 3, at 136, 153; JASON, *supra* note 10, at 40, 59; Technology Assessment, *supra* note 10, at 27–28, 36; SATCON2, *supra* note 2, at 8–11 (proposing the creation of a SatHub, as a central point of coordination for information about satellite reflectivity, emissions, locations, etc.), 20–26, 49–54; 2021 Workshop, *supra* note 2, at 244–45. This improvement in the rapid, thorough dissemination of key information about satellite positioning and trajectories, known as "ephemerides," would involve developing an enhanced standard format for publicly available data beyond the current customary reporting of "two-line-elements" that provide in a nutshell summary data about a satellite's location and velocity at any point. SATCON2, *supra* note 2, at 21–25; SATCON1, *supra* note 6, at 7; 2021 Workshop, *supra* note 2, at 246; Bassa, Hainaut & Galadi-Enriquez, *supra* note 44, at 14 (emphasizing the need for a complete, up-to-date data base of satellite locations and trajectories); FCC Fact Sheet, *supra* note 56, at 36–40 (discussing sharing more information about satellite pathways in order to enhance space situational awareness); Goldstein, *supra* note 91 (noting that SpaceX now provides updates about the positions of Starlink satellites three times per day, acknowledging that the precise location information becomes obsolete in about eight hours).

156. 2020 Workshop, *supra* note 3, at 38, 147 (stressing the vulnerability of radio telescopes to satellite interference and asserting that "These satellites must be rendered invisible to radio telescopes."); Handbook, *supra* note 6, at 58–63 (noting the difficulty of sharing radio frequencies between observatories and other users, because astronomy seeks signals that are so much weaker than other terrestrial and satellite sources transmit; opining that global problems of interference can be resolved only by the ITU); Eves, *supra* note 84 (describing mechanisms through which a LEO satellite can avoid interference, such as by altering its orientation or switching off its transmitters); Peel, *supra* note 19; JASON, *supra* note 10, at 70–71; Jason Rainbow, *Starlink and OneWeb Reach Spectrum Coordination Plan*, SPACE NEWS (June 14, 2022), https://spacenews.com/starlink-and-oneweb-reach-spectrum-coordination-plan/ [https://perma.cc/BHE5-V675] (archived Sept. 25, 2023) (reporting agreement between satellite communications companies to share use of the electromagnetic spectrum, but not taking into account the interests of astronomy); Cavallaro, *supra* note 28 (proposing a requirement that satellite "operators steer their satellites' beams away from the telescope site, a measure which would require a simple software modification with no repercussion on the constellation's deployment, positioning or hardware"); FCC 2021 Order, *supra* note 55, at 49–50 (FCC notes that Starlink has complied with the

Deorbit a satellite promptly after its functionality ends. This practice would reduce the harm to astronomy at little cost to the services provided by the satellite constellation.[157]

Further study of satellite and constellation designs. Satellite companies could prioritize, including via the use of detailed pre-flight simulations, analysis of the effects that future satellite designs and constellations might have on ground-based and orbital observatories, and incorporate that knowledge into future construction.[158] Additional consultations between satellite operators and astronomers could help develop a more thorough hierarchy of specific design and operational features that cause a constellation to pose greater or lesser harm to observatories in general, or to specified observatories in particular.[159]

B. *Adjustments by Observatories*

On the other side of the coin, there are accommodations that could be implemented by the ground- and space-based astronomers as well to mitigate the harm they suffer. Different observatories will be affected differently by the intruding satellite light and noise, so no

---

requirements to coordinate its use of radio spectrum with other users); Technology Assessment, *supra* note 10, at 34–35 (noting that even if satellite operators turn off the radio signals when the satellite is directly over a radio quiet zone, transmissions from side bands may still interfere with the observatory's receivers).

157. 2020 Workshop, *supra* note 3, at 134–35 (discussing procedures and timetables for deorbiting satellites at the end of their useful lives); JASON, *supra* note 10, at 41. Under current international standards, a satellite is to deorbit within 25 years of the end of its operational lifetime; for LEO satellites that have expected service lives of about 5 years, this means the total constellation could continue to reflect more sunlight for a much longer period of time than necessary. Revised U.S. standards will implement a five-year deadline for deorbiting. If a satellite fails, and cannot be actively brought down, the process of natural decay may be so slow (depending on its altitude) that the satellite may remain in orbit (and continue to interfere with astronomy) for 12-18 years (for a satellite like Starlink, orbiting at 550 kilometers) or 1000 years (for OneWeb satellites at 1200 kilometers). SATCON2, *supra* note 2, at 221–22; *see* Foust, *Satellite*, *supra* note 91 (noting OneWeb's intention to deorbit a satellite within five years of the end of its mission); Theresa Hitchens, *White House Calls for Review of 25-Year Deadline for De-Orbiting Dead Satellites*, BREAKING DEFENSE (July 29, 2022), https://breakingdefense.com/2022/07/white-house-calls-for-review-of-25-year-deadline-for-de-orbiting-dead-satellites/ [https://perma.cc/Z6AX-GE4M] (archived Sept. 25, 2023) (reporting U.S. government study of possibilities for requiring or recommending quicker deorbiting of satellites at the end of their functionality).

158. 2020 Workshop, *supra* note 3, at 136; JASON, *supra* note 10, at 70–71 (urging that more be done to study and document the effects of large constellations on radio astronomy); Bassa, Hainaut & Galadi-Enriquez, *supra* note 44 (simulating the effects of large LEO constellations); Tyson, *supra* note 60; Hainaut & Williams, *supra* note 17.

159. SATCON2, *supra* note 2, at 209; 2021 Workshop, *supra* note 2, at 76–77 (noting that "Satellite operators are more likely to adopt voluntary practices or mitigation tools if companies engage with astronomers early in their project cycles, before spacecraft designs are finalized and when modifications to architectures, spacecraft design or operations could be introduced at less cost or schedule impact.")

single adaptation will suffice for all, but there may be some useful responsive techniques in common.[160]

Deploy more telescopes, including networked, cooperating facilities in dispersed locations. This approach would pursue the coveted win-win solution, but financial costs and licensing difficulties pose continuing, substantial barriers to the proliferated construction of additional facilities.[161]

Move more telescopes to space (including on or around the Moon). This, too, would be scientifically advantageous, and to some extent is the path already pursued by mammoth projects such as the Webb Telescope and its planned successor, the Nancy Grace Roman Space Telescope.[162] However, the costs are daunting again, and even a LEO telescope does not entirely escape the deleterious effects of the light and noise of surrounding satellite constellations. Moreover, the technical challenges, including the inherent difficulty in maintaining or upgrading an orbital facility, are formidable.[163] ·

---

160. SATCON1, *supra* note 6, at 65–83 (noting that different observatories will be affected in different ways by LEO satellite interference; ranking some of the principal programs by the degree of anticipated impact); Witze, *supra* note 77; European Organization, *supra* note 140 (reporting that the effects of satellite interference will be manageable for European Southern Observatory); Moro-Aguilar, *Potential Need*, *supra* note 43, at 498.

161. 2020 Workshop, *supra* note 3, at 145–46 (emphasizing the value of networked telescopes); Bassa, Hainaut & Galadi-Enriquez, *supra* note 44, at 16 (contemplating the idea of installing an auxiliary camera mounted in parallel with the main telescope). When one important telescope suffers a catastrophic failure, such as the 2020 collapse of the immense radio telescope at Arecibo, Puerto Rico, it has proven prohibitively expensive to restore it. Meghan Bartels, *Scientists Want to Build a New, Very Different Arecibo Telescope to Replace Fallen Icon*, SPACE.COM (July 22, 2021) https://www.space.com/arecibo-telescope-replacement-process-and-designs [https://perma.cc/QDJ3-BBQT] (archived Sept. 26, 2023); Alexandra Witze, *Legendary Arecibo Telescope Will Close Forever—Scientists Are Reeling*, NATURE (Nov. 19, 2020), https://www.nature.com/articles/d41586-020-03270-9 [https://perma.cc/2E9W-M2NF] (archived Sept. 26, 2023); Alexandra Witze, *Renowned Arecibo Telescope Won't Be Rebuilt – and Astronomers Are Heartbroken*, NATURE (Oct. 17, 2022), https://www.nature.com/articles/d41586-022-03293-4 [https://perma.cc/96L3-RH28] (archived Sept. 26, 2023).

162. *Introducing the Nancy Grace Roman Space Telescope*, NASA https://roman.gsfc.nasa.gov/ [https://perma.cc/HHH4-K8TV] (archived Sept. 26, 2023); Robert Lea, *The Nancy Grace Roman Space Telescope Will "Rewind" the Universe. Here's How*, SPACE.COM (Apr. 10, 2023), https://www.space.com/nancy-grace-roman-space-telescope-simulation-early-universe [https://perma.cc/4857-XTYS] (archived Sept. 26, 2023); Jon Kelvey, *How Spy Satellite Tech Will Power NASA's Next Big Telescope*, INVERSE (Feb. 6, 2022) https://www.inverse.com/innovation/nancy-grace-roman-space-telescope-dark-energy-nasa [https://perma.cc/BGY4-2RHJ] (archived Sept. 26, 2023); Tereza Pultarova, *China Wants to Launch a Moon-Orbiting Telescope Array as Soon as 2026*, SPACE.COM (Jun. 9, 2023), https://www.space.com/china-moon-orbiting-radio-telescope-2026 [https://perma.cc/YRQ5-CNSH] (archived Sept. 26, 2023) (describing China's plans for a radio telescope orbiting around the Moon).

163. 2020 Workshop, *supra* note 3, at 149–50 (noting that space telescopes can complement ground-based telescopes, but cannot perform all their missions, due to prohibitive technical challenges); SATCON2, *supra* note 2, at 80 (noting that space-based

Do more to direct the telescopes away from the brightest, noisiest, most numerous satellites, or close the telescope's shutter when an offending satellite is in view. Artificial intelligence may help calculate which sectors of the sky, at which times of night and which seasons of the year, would be most felicitous for astronomy. If the telescopes can be made more nimble, they may still be able to explore the remaining, and diminishing, pristine swaths of the sky. However, observatories that specialize in surveying a wide field of the sky will have much less opportunity to pursue this type of adaptation.[164]

---

astrophotography is not immune from interference by LEO satellite clusters); Shannon Hall, *Hubble Telescope Faces Threat from SpaceX and Other Companies' Satellites*, N. Y. TIMES (Mar. 2, 2023), https://www.nytimes.com/2023/03/02/science/hubble-spacex-starlink.html [https://perma.cc/L9D7-KSE3] (archived Sept. 26, 2023) (reporting that an increasing percentage of the space imagery collected by the Hubble Telescope is spoiled by streaks from passing satellites, and quoting astronomer Jonathan McDowell saying that because of the growing interference, "There will be science that can't be done. There will be science that's significantly more expensive to do. There will be things that we miss."); Richard Green, Margarita Metaxa, Pedro Sanhueza & Constance E. Walker, Turn on the Night! Science and Education on Dark Skies Issues, Proceedings of IAU Symposium No. 367, (Dec. 2020), https://ui.adsabs.harvard.edu/abs/2021IAUS..367..323W/abstract [https://perma.cc/82LA-YG4Y] (archived Nov. 15, 2023) (emphasizing that space-based telescopes are also impacted by interference from LEO constellations, and mitigations will be more challenging to implement for them); Nat'l Acads., *supra* note 27 (recommending multi-billion dollar space-based telescopes to study ultraviolet, visible, infrared and radio signals); Jeff Foust, *Unlocking the Next Great Observatories*, SPACE REVIEW (Jan. 16, 2023), https://www.thespacereview.com/article/4515/1 [https://perma.cc/J6TT-N4ZU] (archived Sept. 26, 2023) (describing future generations of space telescopes, while noting that "Funding, of course, has been a perennial challenge for NASA"); Foust, *supra* note 27; Overbye, *supra* note 26; Ian Crawford, *Building Telescopes on the Moon Could Transform Astronomy, and It's Becoming an Achievable Goal*, SPACE REV. (May 1, 2023) https://www.thespacereview.com/article/4575/1 [https://perma.cc/26W5-6EBX] (advocating that the Moon would be an exceptionally favorable location for conducting radio and infrared astronomy); Arwen Rimmer, *You Can't Take the Sky from Me*, SPACE REV. (Jan. 13, 2020), https://www.thespacereview.com/article/3864/1 [https://perma.cc/X79K-SHA5] (archived Sept. 26, 2023) (suggesting that SpaceX and other communications companies should pay for one new space telescope for every 100 satellites they put into LEO); Lyndie Chiou, *Satellites Threaten Astronomy, But a Few Scientists See an Opportunity*, N.Y. TIMES (Apr. 17, 2023), https://www.nytimes.com/2023/04/17/science/astronomy-starlink-spacex-kuiper-amazon.html [https://perma.cc/45YC-XG7V] (archived Sept. 26, 2023) (some scientists suggest placing small gamma ray detectors on satellites in large commercial constellations, to gather valuable scientific data).

164. *See* JASON, *supra* note 10, at 42 (recommending that the Rubin Telescope alter its intended observational strategy by collecting two smaller images instead of a single larger one, even though that would sacrifice 8% of its observing time, because doing so would help dodge some effects of illuminated satellites passing through the images); SATCON1, *supra* note 6, at 55–58 (discussing better scheduling of observations and active shuttering of camera lenses); Hainaut & Williams, *supra* note 17, at 10 (discussing possibilities for directing a telescope away from the offending satellites or interrupting

Develop and widely share additional improved filters and software tools and techniques to compensate for the interference caused by satellites. To some extent, images may be rescued by erasing the streaks; where data is lost due to the inability to see behind the satellites' glare, the telescope could be programmed to revisit the relevant sector of the sky.[165] It may also be possible to develop smarter instruments, which could someday subtract or mask the effect of extraneous satellite-reflected light.[166] Similarly, there are post-processing data manipulation techniques available to radio observatories to repair (but not to eliminate) the effects of satellite interference.[167]

---

the telescope's observations when a satellite is overhead, and noting that these accommodations will not be possible for all observatories); Tyson, *supra* note 60, at 2,3 (concluding that "dynamic avoidance of the large number of LEOsats will be challenging"; a telescope will be able to collect valuable observations only "when it gets lucky and stumbles into an open patch of sky"); Bassa, Hainaut & Galadi-Enriquez, *supra* note 44, at 14 (considering the possibilities for redirecting a telescope or closing its shutter when an interfering satellite comes within its field of view, and concluding that such adaptations would introduce more complexity into the scheduling process and would still not resolve all issues); Halferty, *supra* note 75; Alexandra Witze, *SpaceX Tests Black Satellite to Reduce "Megaconstellation" Threat to Astronomy*, NATURE (Jan. 9, 2020), https://www.nature.com/articles/d41586-020-00041-4 [https://perma.cc/T8MD-CGDR] (archived Sept. 26, 2023) (quoting astronomer Tony Tyson saying that swiveling a telescope to avoid satellites would be feasible when there are 1000 satellites in orbit, but not when there are tens of thousands).

165. *Asteroids and Comets*, APOLLO ACADEMIC SURVEYS (Aug. 29, 2022), https://deploy-preview-12--apollo-surveys.netlify.app/asteroids-and-comets/ [https://perma.cc/2GDL-Z4JJ] (archived Sept. 27, 2023) (reporting varying assessments by planetary defense astronomers, with some suggesting that appropriate software could be developed to filter out most interference from artificial satellites, and others anticipating severe consequences from the LEO constellations); Stefanie Waldek, *Asteroid Hunters Worry Megaconstellations Might Interfere with Planetary Defense*, SPACE.COM (Sept. 1, 2022), https://www.space.com/asteroid-detection-interference-from-satellites [https://perma.cc/QP6Q-XG69] (archived Sept. 27, 2023); SATCON2, *supra* note 2, at 33–46 (recommending the development of software that could flag, mask, and repair satellite trails on imagery); JASON, *supra* note 10, at 41 (calling for governmental support of the development of appropriate new software tools); SATCON1, *supra* note 6, at 52–53; Bassa, Hainaut & Galadi-Enriquez, *supra* note 44, at 16 (highlighting methods for *a posteriori* subtraction of satellite tails from a telescope's data, but noting that some of the lost data will be unrecoverable); Hall, *supra* note 171 (noting that the Hubble space telescope acquires images that are then stacked on top of each other, a method that erases streaks caused by satellites, but this technique is much less effective when the telescope is surveying wide expanses of sky); Barentine, Venkatesan, Heim, Lowenthal, Kocifaj & Bará, *supra* note 63, at 256 (critiquing efforts at data treatment).

166. 2020 Workshop, *supra* note 3, at 151 (recommending development of improved software for observatories), 149 (describing improved instruments as a "far-future mitigation" that might help with some detection missions); SATCON1, *supra* note 6, at 6; Witze, *supra* note 77.

167. 2020 Workshop, *supra* note 3, at 175; JASON, *supra* note 10, at 66 (finding that radio interference "from megaconstellations is projected to be strong, pervasive, and difficult to avoid or mitigate"; attempting to deal with the problem via signal processing "is found not to be robust"); 2021 Workshop, *supra* note 2, at 77 (calling on the countries that support large constellations of satellites to provide the resources necessary to

For radio astronomy, develop the concept of a radio "dynamic zone." In partial contrast to the existing "quiet zones," a radio dynamic zone would facilitate experimentation with novel transmitters, receivers, and techniques to share the radio spectrum more creatively and cooperatively. The concept would be to test potential mechanisms for more intensive collaboration in exploitation of the frequencies of mutual interest.[168]

Hardware accommodations for radio telescopes could include deployment of a "reference antenna," a separate small device that can help cancel radio interference from space, or development of a more robust radio receiver, which can cope better with signal spikes from satellites while preserving access to the data from distant space.[169]

Obviously, many of these potential remedies will cost money; perhaps truly major infusions of new cash would be required, beyond any level that might realistically be forthcoming. But this may also be a situation in which the traditional award of appropriate financial compensation for loss would simply not be sufficient. That is, an observatory exists to undertake a particular science mission or set of missions, and reimbursement for the diminution of their effectiveness would seem almost irrelevant to many astronomers. Unlike profit-seeking private corporations that respond to market incentives, observatories could not reasonably calculate the value of contaminated images and foregone discoveries—the focus is intensely on the scientific data collected, not on its commercial worth. As long as the interference persists, the social harm continues, and financial indemnification would not truly compensate for the loss to astronomers or society, or make them whole.[170] As one leading astronomer put it,

---

sustain astronomical observation data acquisition); Foust, *Concerning Threat*, *supra* note 84.

168. Christopher Gordon De Pree, Christopher R. Anderson & Mariya Zheleva, *A Solution to the Growing Problem of Satellite Interference with Radio Astronomy*, SPACE REV. (Mar. 20, 2023) https://www.thespacereview.com/article/4550/1 [https://perma.cc/3MLT-6JUL] (archived Sept. 27, 2023).

169. Technology Assessment, *supra* note 10, at 36; JASON, *supra* note 10, at 71.

170. 2020 Workshop, *supra* note 3, at 150 ("Even if all mitigations above were implemented, astronomy will pay dearly. The exact damage is impossible to estimate: one cannot put a price on lost science opportunities. How does one estimate the risk of stymying the utility of ground-based telescopes? How does one calculate how public knowledge and appreciation of the universe will suffer when we miss out on new exciting and unpredictable discoveries? What we can say is that the presence of tens of thousands of satellites will decrease the time available for uncontaminated, satellite-free observations across the world. All observatories planet-wide will be affected, to varying degrees. The upcoming contamination will degrade the legacy that each and every observatory leaves to future generations: its data archives."); RUBIN OBSERVATORY, *supra* note 74, at 3 (commenting that the impact on science from satellite interference

the compromise of a dark and quiet sky "potentially threatens the science of astronomy itself."[171] The possibility of equitable relief, in the form of an injunction (or a statute or regulation that mandated restraint or remedial behavior) may be more appropriate than financial payoffs.[172]

Moreover, as a practical matter, it may be impossible to fully reconcile the competing interests here. Even if satellite operators and astronomers cooperate with full good faith and mutual accommodation, some residue of interference is inescapable. Evidence of the satellite streaks across the observatories' imagery will be unavoidable, forfeiting or corrupting some data, complicating the analysis of acquired data, requiring repeated observations of the same sector of space, and thereby impeding scientific discoveries and the resultant societal benefits.[173]

---

goes beyond efficiency loss, and complicates or prevents important observations); Handbook, *supra* note 6, at 4 (observing that it is difficult to assess the full economic value of radio astronomy and the benefits that would be foregone by its diminution); 2021 Workshop, *supra* note 2, at 128–29 (addressing the difficulty in assessing compensation for damage inflicted on astronomy by large LEO constellations); Hainaut & Williams, *supra* note 17, at 1 (highlighting the "emotional and moral dimensions of the issue"); Bassa, Hainaut & Galadi-Enriquez, *supra* note 44, at 16 (noting the costs of adjusting to satellite interference and the fact that despite all possible mitigations, some important data will be lost forever); Brian Sheen, *Mega Constellations and Their Impact on Astronomy*, ROOM (JuneJun 4, 2020), https://room.eu.com/community/mega-constellations-and-their-impact-on-astronomy [https://perma.cc/QB3Y-REAB] (archived Sept. 27, 2023) (noting both that the satellite interference will cause astronomers to irretrievably lose some data and that observatories can make some adjustments to compensate for the interference, but doing so will cause a diversion of time and money away from the primary science functions and into the study and implementation of mitigating measures); Barentine, Venkatesan, Heim, Lowenthal, Kocifaj & Bará, *supra* note 63, at 253.

171. Shannon Hall*, As SpaceX Launches 60 Starlink Satellites, Scientists See Threat to "Astronomy Itself*,*"* N. Y. TIMES, (Nov. 11, 2019) https://www.nytimes.com/2019/11/11/science/spacex-starlink-satellites.html#:~:text=%E2%80%9CIf%20there%20are%20lots%20and,tracks%20objects%20in%20orbit%2C%20agrees. [https://perma.cc/KQK7-EVRD] (archived Sept. 27, 2023) (quoting James Lowenthal) (also quoting astronomer Jonathan McDowell saying "There is a point at which it makes ground-based astronomy impossible to do.").

172. COLOGNE COMMENTARY, *supra* note 95, at vol. 1, p. 141 (discussing damages awards under general international law and the OST).

173. COLOGNE COMMENTARY, *supra* note 95, at vol. 2, p. 100, 113 (emphasizing that the Liability Convention incorporates a "victim-oriented" and "unlimited" system, including "full reinstatement to the situation prior to the damaging incident"); SATCON2, *supra* note 2, at 14 (Concluding that "no combination of mitigations can fully eliminate the impact of satellite trails on the science programs of current and planned ground-based optical, [near infra-red], and radio astronomy facilities"); B. Ashley Zauderer-VanderLey, Dark and Quiet Skies for Sci. and Soc'y II, , Powerpoint Presentation at the conference of United Nations Office for Outer Space Affairs: Impacts to U.S. Ground-based Facilities, (Oct. 3-7, 2021), at. 33, https://www.unoosa.org/documents/pdf/psa/activities/2021/DQS2021/Day3/Sess11/D3S11_8_SCWG_AshleyZaudererVanderLey_converted.pdf [https://perma.cc/CFH8-YS6E] (archived Sept. 27, 2023); Handbook, *supra* note 6, at 107 (observing that interference

C. *Mechanisms for Establishing a Solution*

Independent of whatever solutions are ultimately developed to reconcile the competing interests here, there are a variety of possible institutional mechanisms for recording, promulgating, and enforcing the new standards. They are listed here in no particular order, and it is important to note that individuals, groups, or society could elect to pursue more than one path; these routines could be drawn upon sequentially or simultaneously to propagate an effective response. (For convenience, these options are expressed here mostly in terms applicable to the satellite industry, but many of them could be readily flipped for application to the astronomy community, too.)

Voluntary behavior. The satellite industry and similarly-situated governmental agencies could individually or collectively undertake, in a non-legally-binding fashion, to self-regulate—i.e., to voluntarily revise their behaviors in any of the ways indicated above. These self-restraint commitments could be expressed orally or in writing, and nationally or globally, perhaps under the rubric of industry best practices, a corporate code of conduct, or rules of the road.[174] Together with the observatories, they could establish an

---

leads to both the loss of data and the loss of data quality); Tyson, *supra* note 60, at 12 (noting the impossibility of predicting what scientific discoveries will be foregone if astronomy is compromised by satellite interference, and observing that many of the same characteristics that make the Rubin Observatory so promising in the search for unexpected space phenomena also make it especially vulnerable to interference); Cavallaro, *supra* note 28 (foreseeing that large constellations of satellites could "threaten the viability of the complete [key radio frequency band utilized by the Square Kilometer Array observatory] 100% of the time, unless stringent mitigation actions are put in place.")

174. SATCON2, *supra* note 2, at 128–30, 205–08, 214–15 (reporting discussions with satellite operators' industry groups regarding voluntary practices and mitigation tools); NASA FCC Letter, *supra* note 30, at 4 (urging creation of "best practices"); Kevin Conole, *U.S. Statement on Dark and Quiet Skies*, U.S. MISSION TO INTERNATIONAL ORGANIZATIONS IN VIENNA (Feb. 17, 2022), https://vienna.usmission.gov/2022-copuos-stsc-dark-and-quiet-skies/ [https://perma.cc/8GQ9-LUTW] (archived Sept. 27, 2023) (endorsing voluntary best practices guidelines developed by industry regarding satellite design); *Best Practices for the Sustainability of Space Operations*, SPACE SAFETY COALITION (May 2023), https://spacesafety.org/best-practices/ [https://perma.cc/HDZ5-KTGC] (archived Sept. 27, 2023); T. Maclay, W. Everetts & D. Engelhardt, *Responsible Satellite Design and Operational Practices: A Critical Component of Effective Space Environment Management (SEM)*, 70TH INTERNATIONAL ASTRONAUTICAL CONGRESS, October 21–25, 2019, https://assets.staging.oneweb.build/s3fs-public/assets/documents/Responsible-Satellite-Design-and-Operational-Practices-A-Critical-Component-of-Effective-Space-Environment-Management-SE.pdf [https://perma.cc/3PWN-XGMX] (archived Sept. 27, 2023) (representatives of leading space companies OneWeb, Iridium, and Maxar outline a series of proposals to strengthen the protection of the space environment); Moro-Aguilar, *Potential Need*, *supra* note 43, at 498–99 (discussing prospects for, and limitations of, self-regulation by satellite

"astronomy rating system," to publicly endorse the satellites and companies that were doing the best job of mitigating the light and noise effects (or, in a more negative posture, to name and shame those who were not performing adequately).[175]

Federal regulations. If voluntary measures prove insufficient to generate the desired behavior by space companies and observatories, some degree of official compulsion may be necessary. One avenue for making any new brightness and noise rules legally binding in the United States would be to incorporate them into formal federal regulations and licensing standards, to be adopted by the Federal Communications Commission or another entity with jurisdiction over the permitting of space flight and operations.[176] These would then become controlling insofar as US actors were concerned, and there

---

companies); BYERS & BOLEY, *supra* note 34, at 94–98. *See also* INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, https://www.iso.org/home.html [https://perma.cc/NB9L-VDP2] (archived Sept. 27, 2023) (international organization that develops and promulgates standards on a wide array of subjects).

175. *See* SPACE SUSTAINABILITY RATING, https://spacesustainabilityrating.org/ [https://perma.cc/Z7YJ-DLGH] (archived Sept. 27, 2023); *Space Sustainability Rating*, WORLD ECON. FORUM, https://www.weforum.org/projects/space-sustainability-rating [https://perma.cc/H4LK-YQCX] (archived Sept. 27, 2023). As noted, SpaceX is the industry leader in developing and implementing mitigation techniques and has repeatedly undertaken voluntary measures of this sort to reduce the perceived brightness of Starlink satellites via a variety of experimental modifications, including DarkSat and VisorSat. Among its current mitigation efforts are plans to reorient the most reflective satellite components away from Earth at critical moments, to use an extremely dark, absorptive paint on exposed surfaces, and to coat satellite bodies with a dielectric film that will direct the most harsh reflections away from Earth. SpaceX has also volunteered to provide the innovative paint and coating materials to other space companies at cost. White Paper, *supra* note 50; *Second Generation*, *supra* note 38, at 3 (asserting that "SpaceX will work tirelessly to refine design/manufacturing/materials and operational mitigations and continue to work with astronomers toward reducing the brightness of our satellites."). The efficacy of these measures in mitigating the problems for astronomy has not yet been established in detail.

176. U.S. law divides regulatory authority over commercial space activities among several federal agencies, each of which might play a role in enhancing the protection for observatories: the FCC regulates use of the radio spectrum; the National Oceanic and Atmospheric Administration regulates commercial remote sensing; and the Federal Aviation Administration regulates launch and recovery of spacecraft. GOV'T ACCOUNTABILITY OFF., GAO-23-105005: FCC SHOULD REEXAMINE ITS ENVIRONMENTAL REVIEW PROCESS FOR LARGE CONSTELLATIONS OF SATELLITES at 11–12 (Nov. 2, 2022), [hereinafter GAO FCC] https://www.gao.gov/assets/gao-23-105005.pdf [https://perma.cc/PAE3-M6AA] (archived Sept. 27, 2023). In practice, the FCC's licensing authority over the radio spectrum has provided a basis for the agency to regulate additional aspects of space operations, such as the creation of space debris, pursuant to the general statutory authority to determine "whether the public interest, convenience, and necessity will be served." Communications Act of 1934, 47 U.S.C. § 309(a). *See also* Moro-Aguilar, *Potential Need*, *supra* note 43, at 500 (suggesting that FCC regulation of the radio spectrum to protect radio astronomy could be a model for future regulation designed to protect optical astronomy); Boyle, 2023, *supra* note 45 (reporting that "Several astronomers say new rules from the FCC would not be enough" because other countries would adopt different rules.)

could be a parallel undertaking to try to inspire copycat instruments in other countries.[177]

Federal statute. One step higher on the legal hierarchy would be for Congress to enact new standards, officially establishing a different, mutually protective, whole-of-government approach to the relationship between space operators, astronomers, and regulators.[178]

International code of conduct. There has been substantial success in establishing (and some success in implementing) non-legally binding international codes of conduct for space, through the UN Committee on the Peaceful Uses of Outer Space or other venues.[179] Prominent examples include the guidelines on the mitigation of space debris[180] and on the long-term sustainability of space activities.[181] An

---

177. *See* FCC 2021 Order, *supra* note 55, at 49 (regulators acknowledge that SpaceX has been experimenting with different methods for reducing the impact of the Starlink constellation on observatories, decide that "SpaceX must continue its efforts to fulfill its commitments to the astronomy community," and promise that "we will continue to monitor this situation and SpaceX's efforts to achieve its commitments in this record"); FCC 2022 Order, *supra* note 30, at 47–52; 2020 Workshop, *supra* note 3, at 156; SATCON2, *supra* note 2, at 125–27 (calling for U.S. satellite licensing authorities to take into account the adverse impact that satellite constellations will have on other space users); Foust, *FCC Approves*, *supra* note 56 (reporting new FCC rule requiring more prompt deorbit of non-functional satellites, with one commissioner suggesting that this rule would provide an opportunity to establish a *de facto* global standard); Moro-Aguilar, *supra* note 65, at 7 (calling for states to adopt stronger licensing conditions for satellite operators to protect astronomy, such as via FCC regulations to prevent light pollution of the night sky); DE ZWART & LISK, *supra* note 35, at 45 (suggesting that OST art. IX on non-interference could provide the basis for regulatory action in Australia regarding LEO satellite constellations and ground-based observatories).

178. Moro-Aguilar, *supra* note 65, at 7 (noting legislation in the United Kingdom to impose conditions on satellite operators to prevent contamination of space or adverse changes to the space environment).

179. *See generally*, *Committee on the Peaceful Uses of Outer Space*, U.N. OFF. FOR OUTER SPACE AFFS., https://www.unoosa.org/oosa/en/ourwork/copuos/index.html [https://perma.cc/Q33G-P24A] (archived Sept. 27, 2023); *see generally* UNOOSA, ANNUAL REPORT 2021, https://www.unoosa.org/documents/pdf/annualreport/UNOOSA_Annual_Report_2021.pdf [https://perma.cc/9KBC-9CVP] (archived Sept. 27, 2023); LYALL & LARSEN, *supra* note 9, at 14–18; *see* BYERS & BOLEY, *supra* note 34, at 113 (calling for action by COPUOS or the U.N. General Assembly).

180. *Compendium of Space Debris Mitigation Standards Adopted by States and International Organizations*, U.N. OFF. FOR OUTER SPACE AFFS., https://www.unoosa.org/oosa/en/ourwork/topics/space-debris/compendium.html [https://perma.cc/6E4L-KGJR] (archived Sept. 27, 2023); Profit or Safety, *supra* note 9, at 543–45; Comm. on the Peaceful Uses of Outer Space, Rep. on Its Sixty-Fifth session, U.N. Doc. A/77/20 (Jun. 2022), at 13–14, [hereinafter STSC Report], https://documents-dds-ny.un.org/doc/UNDOC/GEN/221/025/6E/PDF/2210256E.pdf?OpenElement [https://perma.cc/J4YL-N5VE] (archived Sept. 27, 2023) (discussing implementation of debris mitigation standards).

181. *See* text accompanying note, *supra* note 142 (discussing long-term sustainability guidelines); Profit or Safety, *supra* note 9, at 558–61; Peter Martinez, *The Development and Implementation of International UN Guidelines for the Long-Term*

addendum to address satellite interference with astronomy would nicely fit that pattern.[182]

Regulation through the ITU. Expanding upon the existing corpus of international legal Radio Regulations, the member states of the ITU could adopt additional constraints, and reinvigorated enforcement, about LEO satellite radio frequency allocations and operations to provide further protection for radio observatories.[183]

Treaty. The superior legally binding form of international agreement is a treaty, which could in principle be negotiated to establish the new standards as mandatory for all countries that elect to sign and ratify the instrument.[184]

Private litigation in domestic courts. Litigation brought by astronomers, based on the rationale of the Liability Convention through domestic tort or environmental law, could be lodged against satellite companies or states in the courts or with administrative agencies of the United States or other countries.[185] Notably, the

---

Sustainability of Outer Space Activities, ADVANCES IN SPACE RSCH. (Jun. 24, 2022) https://www.sciencedirect.com/science/article/pii/S0273117722005312 [https://perma.cc/VMA5-C5YA] (archived Sept. 27, 2023); *Space Sustainability: The Time to Act Is Now*, EMEA SATELLITE OPERATORS ASSOCIATION (Sept. 2021) https://astroscale.com/space-sustainability-the-time-to-act-is-now-says-esoa/ [https://perma.cc/KL3M-C5AQ] (archived Sept. 27, 2023); STSC Report, *supra* note 180, at 16–19 (reporting additional work on long-term sustainability guidelines).

182. 2021 CRP, *supra* note 6, at 3 (asserting that "the mitigation of the effects caused by satellite constellations calls for an internationally agreed regulation," specifically via the U.N. Committee on the Peaceful Uses of Outer Space).

183. Handbook, *supra* note 6 at 13–17 (describing International Telecommunication Union system for allocating radio frequency among various applications); *see* LYALL & LARSEN, *supra* note 9, at 189–225 (discussing structure and operation of ITU); Ruth Pritchard-Kelly, WRC-23 on the Horizon: Large Satellite Constellations, ITU Issues, and Industry Perspectives (Special Issue), 48 AIR & SPACE L., 179, 179 (2023) (discussing ITU regulation of large satellite constellations); Rimmer, *supra* note 163 (calling for heightened ITU regulation of LEO satellite use of radio frequencies of key interest for observatories).

184. 2020 Workshop, *supra* note 3, at 157 (noting that "International law applicable to astronomy is scarce"); SATCON2, *supra* note 2, at 77 (calling for better international regulation and enforcement of the satellite constellation industry); Moro-Aguilar, *Potential Need*, *supra* note 43, at 489 (concluding that existing international regulation is insufficient to protect astronomy from satellite constellations, and "current efforts at self-regulation are giving at best limited results" so "new legal rules will be necessary"); Witze, Astronomers Push for Global Debate, *supra* note 77 (reporting different views of United States, Canada, and Japan, compared to China and Russia, regarding satellite constellations); STSC Report, *supra* note 180, at 21–22 (noting that some states have called for internationally agreed regulation regarding the problem of dark and quiet skies).

185. One successful illustration of this type of litigation was a suit by a French environmental group opposing Starlink's operations on the grounds that an environmental assessment should have been undertaken, including studying the effect of the satellite constellation on the visibility of stars at night. Tom Bateman*, Amazon Targets Elon Musk's Starlink with Dozens of Project Kuiper Satellite Broadband Launches*, EURONEWS (Apr. 6, 2022) [https://perma.cc/AA89-R6GY] (archived Sept. 29, 2023). *See also* Ruskin Hartley,*IDA Appeals FCC Approval of SpaceX Gen2 Satellite*

Liability Convention establishes "absolute" liability for damage inflicted on Earth, so it would not be a sufficient defense for a satellite operator to establish that it had behaved in good faith, without negligence or fault, and in conformity with industry best practices.[186]

Litigation in international courts. Some international courts (such as the International Court of Justice) restrict access in "contentious cases" only to states, so a private observatory would need its claim to be espoused by its national government.[187] But it might be possible in the alternative to engage the court's "advisory" jurisdiction, upon request by the UN General Assembly or other suitable institution.[188] Other international courts (such as the European Court of Justice) are sometimes open to individuals to directly file a claim.[189]

Constellation, (Jan. 6, 2023), https://www.darksky.org/ida-appeals-fcc-approval-of-spacex-gen2-satellite-constellation/ [https://perma.cc/XBW4-E2PE] (archived Sept. 29, 2023) (the International Dark-Sky Association announces an "unprecedented" resort to the court system to resist cumulative damage to night sky brightness).

Note that this Article does not explore the complex set of issues regarding the doctrine of self-executing treaties and the creation of a private right of action under a treaty, which can pose special problems for potential plaintiffs in U.S. courts (but not necessarily in other legal systems). *See* Kirchner, *supra* note 105, at 5 (discussing procedural and cost impediments against potential private litigation brought by astronomers in national courts); Boley & Lawler, *supra* note 2, at 6 (recommending revision of national laws to lower the barriers for private entities seeking to recover damages through the international liability regime); DAVID SLOSS, THE OXFORD GUIDE TO TREATIES, 367 (Duncan B. Hollis, 1st ed. 2012) (discussing the doctrine of self-executing treaties); Carlos Vazquez, *The Four Doctrines of Self-Executing Treaties*, 89 AM. J. INT'L L. 695, 695–697 (1995).

186. LIAB, *supra* note 95, at art. II. Note that the procedures of the Liability Convention provide that a state may present a claim for compensation for harm inflicted on one of its persons, but also that a private actor may directly assert its own claims. *Id.* art. VIII. Under domestic U.S. law, federal courts have exclusive jurisdiction over any claim for "property damage or loss" resulting from a space activity conducted pursuant to a space license granted by the U.S. government. 51 U.S.C. § 50914(g) (2016).

187. The International Court of Justice is open to litigation only between states that have accepted its jurisdiction. I.C.J., *How the Court Works*, https://www.icj-cij.org/en/how-the-court-works (last visited on Sept. 24, 2023) [https://perma.cc/V97Q-HXVX] (archived Sept. 28, 2023); Francisco Orrego Vicuna, *Individuals and Non-State Entities before International Courts and Tribunals* 5 Max Planck Y.B. U.N. L. 53, 53 (2001) . *See* Rossana Deplano, *The Peaceful Settlement of Space Disputes: Prospects and Challenges*, *in* THE CHANGING CHARACTER OF INTERNATIONAL DISPUTE (R. Buchan, D. Franchini, & N. Tsagourias, eds., 2023) (critiquing the absence of a dedicated dispute-resolution mechanism for addressing international conflicts in space).

188. How the Court Works, *supra* note 187 (discussing advisory proceedings).

189. *Court of Justice of the European Union*,https://www.citizensinformation.ie/en/government_in_ireland/european_government/eu_institutions/european_court_of_justice.html (last visited on Sept. 24, 2023) [https://perma.cc/D8NW-R7KB] (archived Sept. 28, 2023); *see* DE ZWART & LISK, *supra* note 35, at 45 (suggesting that where satellite megaconstellations interfere with humans' ability to see the stars, there might be a basis for a claim of breach of personal rights to religion and culture under the International Covenant on Civil and Political Rights and the International Convention on Economic,

In all of this, it is important to acknowledge that the satellite constellations deployed to date have followed the applicable international and domestic rules—the operators have won approvals from the relevant licensing authorities and have done nothing manifestly illegal. At a deeper level, however, the fundamental, unresolved question is whether the dominant interpretations of legal authority are proper or whether the underlying public policies should be reformed. Who (which side of the debate between astronomers and space companies) should bear the brunt of making adjustments to accommodate the other? Who has the rightful starting point; who needs to be persuaded (or bribed, cajoled or compelled) to change their current operations?

D. *Recommendations*

Where do we go from here? How can the affected communities (and, in some ways, the entire world is becoming an affected community) grapple with the imminent collision between the rights and responsibilities of different types of users of space? This section outlines a few high-level recommendations, starting with an effort to reframe the global portrait for megaconstellations and proceeding toward more granular proposals for fashioning viable solutions.

1. Reframing the Issue. The first, foundational step forward is to alter the prevailing paradigm for thinking about this whole issue. The world seems generally to be proceeding on the implicit premise that the proper configuration of legal and political rights and duties results in the satellite companies being left basically free to do whatever they want to do, in pursuit of commercial opportunities, with the astronomers shouldering the burden of coping, essentially on their own, with the damaging interference. This *laissez-faire* mindset holds that the primary responsibility for dealing with the emerging problems lies properly with the victims.

To be sure, some companies, SpaceX in particular, have engaged in sustained, positive conversations with the scientific community, and have experimented in good faith and at their own considerable expense with inventive variations such as DarkSat, VisorSat, and more recent adaptations, to mitigate the problems. But those voluntary steps carry an air of *noblesse oblige*; more to the point, they have not been adequate to solve the problem, and SpaceX has felt free to discard the laudatory experiments, with no advance notice or negotiation, if commercial circumstances so instruct. And, of course, it is far from certain that the

---

Social, and Cultural Rights). *See also* PERMANENT COURT OF ARBITRATION, OPTIONAL RULES FOR ARBITRATION OF DISPUTES RELATING TO OUTER SPACE ACTIVITIES 5–6 (Dec. 6, 2011), https://docs.pca-cpa.org/2016/01/Permanent-Court-of-Arbitration-Optional-Rules-for-Arbitration-of-Disputes-Relating-to-Outer-Space-Activities.pdf (last visited Sept. 24, 2023) [https://perma.cc/VRS9-9BXV] (archived Sept. 29, 2023) (offering an additional voluntary mechanism for addressing space-related disputes).

creators of other emerging space megaconstellations—both profit-seeking entities and other sovereign states—will feel any continuing imperative at all to accommodate the interests of ground-based and space-based astronomy.

But the world does not have to be organized around the assumption that it is just a matter of grace for the space companies to decide to toss an occasional bone the observatories' way. As suggested above, existing international and domestic law may well apportion the applicable rights and obligations differently; at the very least, it is too early in the narrative to conclude that the alignment of political, economic, legal, and other advantages will wholly and permanently favor the satellites.[190] In short, sometimes, first in time is first in right (and sometimes not).[191]

Hence, the world should now be thinking about refining and enhancing the applicable legal relationships, rather than relying solely on corporate goodwill. No one has a legal right to use space with any absolute guaranty against all interference; everyone must tolerate some degree of disruption from legitimate co-users. But conversely, no one has an absolute right to use space without "due regard" for the spinoff consequences upon others. This is a problem of collective action, and a truly global solution is required: today, it is Starlink and the United States in the vanguard, but other corporations and other states are ascending rapidly along the same fraught trajectory.

---

190. SATCON2, *supra* note 2, at 76 (emphasizing that economic, legal, and political factors will shape technology choices about space); JASON, *supra* note 10 at 37 (recommending that the optical astronomy community should "prepare for the worst, i.e., the possibility in the future of a mostly unregulated set of constellations from a variety of countries, with satellites numbering in the tens of thousands or more"); SATCON1, *supra* note 6, at 12 (comparing the burden that satellite interference poses to the astronomy community to the imposition of "a tax – an unfunded mandate"); Jeff Foust, *Legal Recourse*, *supra* note 152, (reporting that astronomers have no viable legal options for protecting observatories against the impact of large LEO satellite constellations); Kirchner, *supra* note 105, at 1, 6 (opining that "The current prevailing legal opinion appears to be that there is very little in international space law which might prevent private actors from launching a large number of satellites in low earth orbits, despite the impact it has on astronomy" and that "international law is a tool of limited practical value" in this situation, but also that "the idea of voluntary cooperation [between satellite operators and observatories] will be of limited practical value" because a "spirit of cooperation" cannot be enforced.)

191. Lawrence Berger, *An Analysis of the Doctrine That "First in Time Is First in Right"*, 64 NEB. L. REV. 349, 350 (1985) (considering several applications of variations of the "first in time is first in right doctrine," in diverse settings, such as regarding the capture of wild animals, intellectual property, liens, water rights, and nuisance.); *see* DE ZWART & LISK, *supra* note 35, at 46–47 (arguing that pioneer space companies may grab an unfair competitive advantage over later users, and "Existing and early moving mega-constellation operators may have substantial market power by simply reaching and establishing themselves in orbit first thereby preventing up-and-coming operators from accessing orbital slots – making proposals for competing services uneconomical or impractical.")

2. Consultations. One potentially profitable way to begin is via formal international consultations, as envisioned by Article IX of the Outer Space Treaty,[192] a cooperative, but rigorous and goal-oriented procedure intended to generate compromise solutions that would work for all. In fact, it would today be plausible for some OST party to complain that the United States (as the state responsible for the space activities of SpaceX[193]) has already violated Article IX by failing to "undertake appropriate international consultations" before allowing the Starlink launches to proceed and to cause their "potentially harmful interference" with the observatories of other parties.

Less provocative than alleging past and persistent breaches would be the prospective application of Article IX, with a treaty party now requesting consultation concerning the ongoing megaconstellation activities and the prospect of continuing and worsening harmful interference. The fact that Article IX has never been invoked in the past should not preclude a concerned treaty party from activating it now.[194]

Who would be bold enough to initiate such a procedure? Many governments have interests on both sides of the equation—the state benefits both from the operation of the private space companies and from the scientific accomplishments of astronomy. Even more, governments are often direct participants in both enterprises, launching and operating constellations of satellites and simultaneously funding and supporting expensive observatories.[195] It would be asking a lot for a government to stand up against Starlink, OneWeb, and other satellite companies—still more, to challenge the states that sponsor those enterprises, the United States and the United Kingdom.

---

192. OST, *supra* note 1 art. IX ("If a State Party to the Treaty has reason to believe that an activity or experiment planned by it or its nationals in outer space, including the moon and other celestial bodies, would cause potentially harmful interference with activities of other States Parties in the peaceful exploration and use of outer space, including the moon and other celestial bodies, it shall undertake appropriate international consultations before proceeding with any such activity or experiment. A State Party to the Treaty which has reason to believe that an activity or experiment planned by another State Party in outer space, including the moon and other celestial bodies, would cause potentially harmful interference with activities in the peaceful exploration and use of outer space, including the moon and other celestial bodies, may request consultation concerning the activity or experiment.")

193. *See* text accompanying note, *supra* note 1 (discussing a state's responsibility for the space activities of its nationals under OST art. VI.)

194. Moro-Aguilar, *supra* note 65, at 7–8.

195. 2021 Workshop, *supra* note 2, at 230 (noting that "Most countries have a direct interest in the preservation of dark and quiet skies since they run astronomical programs in which considerable human and financial resources are invested."); DE ZWART & LISK, *supra* note 35, at 46 (noting that "Nations with large open spaces and strong cultural connections to the sky, such as Australia and Canada, are placed in a paradoxical position, with megaconstellations providing broad based benefits to marginalised and remote communities through increased access to services at the cost of interference with science and culture.").

But a direct or hostile protest is not required. Under the procedure envisioned by Article IX of the OST, all that is necessary to start a productive new procedure would be for a state to "request consultation," on the basis that it has "reason to believe" that a space activity attributed to another party "would cause potentially harmful interference" with its own activities "in the peaceful exploration and use of outer space."[196] Countries that have significant financial investments in ground-based astronomy, and that have already exercised international leadership regarding the preservation of dark and quiet skies, such as Chile, Spain, South Africa, or Australia,[197] might be moved to undertake such an initiative. And if it would prove too politically risky to confront the United States in such a maneuver, perhaps the procedure could be initiated vis-à-vis China, which will soon also crowd the celestial panorama with its own megaconstellations.

In addition, the Liability Convention specifies that "[a] claim for compensation for damage shall be presented to a launching State through diplomatic channels" and contemplates that diplomatic negotiations may lead to a suitable settlement.[198] If those negotiations are unsuccessful, the parties are to establish a Claims Commission to pursue the matter.[199] Such a claim could be grounded on the harm suffered by an observatory or the indirect harm to the state itself.

Importantly, the concept of "consultations" or "negotiations" in these settings is more than just a promise of empty talk; it requires a good faith commitment to problem-solving. Participants are obligated to take into account the interests of the other side, to pursue workable solutions, and to exercise creativity and self-restraint in the diligent pursuit of a viable compromise.[200]

3. Alter Satellite Megaconstellation and Observatory Practices. The satellite companies and the astronomy community should develop refined practices that can enable both sets of interests to succeed. Foremost among the immediate goals should be the articulation of sustainable performance standards that limit the apparent optical

196. OST *supra* note 1, at art. IX.

197. *See* 2021 CRP, *supra* note 6; 2021 Working Paper, *supra* note 31. *See also* Rotola & Williams, *supra* note 97, at (noting several countries that have stressed the importance of preserving the astronomical sky, including Belgium and Australia).

198. LIAB, *supra* note 95, at art. IX, XIV.

199. *Id.* at art. XIV; Deplano, *supra* note 187.

200. The International Court of Justice has determined in other contexts that an obligation to negotiate in good faith includes more than merely a willingness to talk; it implies a duty to engage in give-and-take, to try to accommodate the legitimate interests of other participants, and to reach a mutually-acceptable solution. *See* North Sea Continental Shelf Cases (Federal Republic of Ger. vs. Den. and Neth.) 1969 I.C.J. Reports 3 46–47; Legality of the Threat or Use of Nuclear Weapons, Advisory Opinion, 1996 263–265 I.C.J. (July 8).

brightness and radio noisiness of the satellites. Experts from all the affected communities could collectively specify a suitable cap on the amount of reflected light, and then allow multiple creative engineering approaches to achieve that level via different techniques: altering the shape, color, or surface coating on a satellite; affixing a shield; twisting its orientation to the Earth; etc. There might be a period of manifold experimentation, with close monitoring of the results, and different configurations of relevant features might eventually prove suitable for different types of satellites and operators.[201]

Similarly, the participants in good faith consultations could negotiate suitable objective criteria to protect the core interests of ground-based radio telescopes. Again, the goal is not perfection—the immense growth in space traffic will surely compromise the efficacy of observatories to some extent. But, mandatory performance criteria could be established and engineers could be set to the task of crafting the specific blueprints for ensuring compliance. Rigorous implementation of ITU frequency allocations and respect for established terrestrial quiet zones should be a minimum safeguard.

Other procedures could be institutionalized too. Constellations should be placed at the lowest suitable orbits, closer to Starlink's 550 kilometers altitude instead of OneWeb's 1200 kilometers, to reduce the hours of nightly illumination. Satellite operators could be compelled at the national or international level to share and update the precise details of all crafts' locations and trajectories, to facilitate efforts to direct telescopes elsewhere, creating an enhanced space situational awareness for astronomy that will benefit other applications, as well. All satellites should be made maneuverable and should be deorbited promptly after their service lives end to reduce the danger of collisions and debris.

All of this likely means increased costs for the satellite companies, which they will endeavor to pass along to their customers. That is as it should be—those who benefit from the enhanced communications and Earth sensing services should be expected to pay the full cost of those amenities, not to offload some of the price onto hapless observatories.[202]

On the other side of the coin, those who support astronomy—including governments, universities, non-governmental organizations,

---

201. *See generally* Brad Young, THE ASTRONOMICAL LEAGUE MAGAZINE, MEGACONSTELLATION SATELLITES: PRACTICAL WAYS AMATEURS CAN HELP 25 , (Mar. 2022) https://www.astroleague.org/files/reflector/MARCH%202022%20REFLECTOR%20pages.pdf (last visited Sept. 24, 2023) [https://perma.cc/ZS4S-QTDA] (archived Sept. 29, 2023) (highlighting the difficulty of measuring satellite brightness accurately and consistently); Technology Assessment, *supra* note 10, at 27.

202. *See* White Paper, *supra* note 50 (describing financial and performance costs that SpaceX has voluntarily borne in order to reduce the harm that satellite reflection imposes on astronomy, and the company's willingness to share the relevant technology with other satellite operators).

and individual benefactors—will also have to cough up more funding to sustain the enterprise in an era where competing uses of space have unfortunately compromised the established routines. In the short term, governments should subsidize the task of developing and proliferating enhanced filters and software for scrubbing the offending white streaks out of the telescopes' imagery.[203] In the longer term, more astronomy will have to move away from the surface of the Earth, into LEO or beyond, including establishing facilities on the Moon (at admittedly immense cost).

4. Accelerate the Public Outreach. In the past three years, astronomers have mobilized an impressive campaign of outreach and education for the profession and the public. Four major international conferences (SATCON1 in June 2020, SATCON2 in July 2021, Dark & Quiet Skies I in October 2020, and Dark & Quiet Skies II in October 2021) have succeeded in raising consciousness about the issues and in defining with more precision how serious the problem is and what mitigation measures can contribute.

Yet more remains to be done to achieve meaningful breakthroughs in a public sphere crowded with diverse topics clamoring for attention. Given the massive public presence of SpaceX, OneWeb, Amazon, and the other satellite services providers, the astronomy community cannot succeed if the concerns about significant interference are allowed to be seen as just a niche issue. The drumbeat of warning must intensify further before it can translate into meaningful political and social pressure for mutual accommodation.

5. Litigate. If the cooperative approaches are insufficient, astronomers should adopt a tougher stance, and begin to litigate. One appropriate avenue would be through the Liability Convention, which includes its own state-administered claims mechanism and also explicitly does not preclude a private actor "from pursuing a claim in the courts or administrative tribunals or agencies of a launching state."[204] In a suitable case, the complaint could be framed in terms of nuisance law (alleging that the bright and radio-noisy satellite overflights disrupted the observatory's ability to use its property in a profitable or productive fashion) or environmental law (invoking principles about not inflicting significant harm, as a type of disruptive pollution, across international boundaries or into areas that are beyond any country's national jurisdiction). The cause of action would be bolstered by the Liability Convention's specification of "absolute"

---

203. *See* Research and Development Strategy, *supra* note 51.

204. LIAB, *supra* note 95, at art. XI.2. Under the treaty, a "launching state" is a state that launches or procures the launching of a space object, or from whose territory or facility the space object is launched. There could be multiple launching states for any particular space object. LIAB, *supra* note 95, at art. I(c).

liability, making the damage-inflicting actor financially responsible even if no negligence, fault, or ill will were established.[205]

The targeted defendant(s) in such a suit could be a private corporation that operates a proliferated LEO constellation, the state that sponsors and oversees that private entity, or both. The aggrieved plaintiff could be an observatory, its home state, or both; perhaps multiple parties' claims could be joined into a class action litigation.[206]

If any state were sufficiently energized, it might pursue a claim that another state that sponsored a megaconstellation had violated the obligation in OST Article IX to conduct its space activities "with due regard to the corresponding interests of all other States Parties to the Treaty."[207] Such a claim would attempt to breathe requisite life into the ill-defined concept of "due regard," offering a substantive companion to the procedural claim, noted above, about a state's failure to initiate appropriate international consultations prior to proceeding with activities that would cause potentially harmful interference with the space activities of others.[208]

Of course, there is no guaranty that any such lawsuits would succeed, and the astronomy community has to date strongly preferred to pursue cooperative approaches and quiet, behind-the-scenes discussions with industry interlocutors. But the option to proceed with a toothier adversarial posture deserves consideration too.[209]

---

205. LEO constellations also interfere with the operations of space-based observatories, so a claim could be brought on their behalf, too, but the Liability Convention provides liability only for "fault" when the damage occurs in space. LIAB, *supra* note 95, art. III. The treaty does not define fault, and there is no relevant state practice in interpreting that concept. It would likely be easy for a putative plaintiff to prove that a particular satellite was the proximate cause of a particular streak across the telescope's imagery, and that the satellite operator acted "deliberately," but it might be problematic to establish legal fault. *See generally* Andrea Capurso, Paolo Marzioli & Michela Boscia, *Questions of Fault Liability: A Case Study Analysis of In-orbit Collisions with Debris*, 10 J. SPACE SAFETY ENG'G 439 (2023).

206. The Liability Convention does not provide for a national to file a claim against its own state. LIAB, *supra* note 95, at art. VII(a).

207. OST *supra* note 1, at art. IX.

208. Goehring, *supra* note 118 (suggesting that the due regard principle could become a functional rule, rather than just a vague legal principle, if states start to assert it vigorously).

209. There is a tricky political judgment here. Some observatories have concluded that confidential discussions with satellite companies would be more productive than public acrimony, but others have suggested that if astronomers do not "squawk" sufficiently, then the public will presume that the satellite brightness is not causing them very much pain. To date, the predominant approach has been to rely on quiet diplomacy to seek to obtain the cooperation of the space companies. *See* CHARLES LEE MUDD, JR., ILL. ST. BAR ASSOC. INTELL. PROP., STARLINK AND MEGA CONSTELLATIONS: FINDING A VIABLE LEGAL SOLUTION 1 (Feb. 2020), https://www.isba.org/sites/default/files/sections/intellectualproperty/newsletter/Intellectual%20Property%20February%202020.pdf (last visited Sept. 29, 2023) [https://perma.cc/WAW2-RBC8] (archived Sept. 29, 2023) (arguing that litigation today would be "misguided, ineffectual, and possibly counterproductive"); SATCON2, *supra*

6. Negotiate New International Agreements. It should not be surprising that existing international law is inadequate to deal with the challenges of today's sensational space technology and revolutionary economics. The main treaties on the topic and the primary institutions that occupy the field were established decades ago and the negotiators could hardly have been sufficiently prescient to have anticipated the modern operational needs. Additional law-making, therefore, is overdue.

One valuable step would be to directly engage the energies of the leading forum for advancing civil space law, the Legal Subcommittee of the UN Committee on the Peaceful Uses of Outer Space (COPUOS). To date, international attention to the problem of suitable preservation of dark and quiet skies has been treated almost exclusively as a scientific matter, and discussion has been confined to the Scientific and Technical Subcommittee of COPUOS. With all due respect to that body, the time has come to share jurisdiction, and member states should empower the Legal Subcommittee to officially adopt this as an agenda item, looking forward to the prompt articulation of a future international agreement on point.[210]

There is also scope for the ITU to flex its muscles, being ceded authority for adopting additional regulations and recommendations to govern radio operations in LEO as vigorously as it has traditionally done for the geosynchronous orbit. Enforcement measures, to ensure dutiful respect for the existing frequency allocations, could also be enhanced.

VII. CONCLUSION

Consider a simple analogy: sequential visitors to a public beach on a warm summer day. The first patrons to arrive can scout out the optimal sites, perhaps focusing on unobstructed views of the waves,

---

note 2, at 14 (favoring a collaborative approach rather than conflict between astronomy and industry).

210. *See* U.N. COMMITTEE ON THE PEACEFUL USES OF OUTER SPACE, REPORT OF THE LEGAL SUBCOMMITTEE, 61st Sess., at ¶¶ 237–239, U.N. DOC., A/AC.105/1260 (Apr. 19, 2022) (reporting discussion about whether the Legal Subcommittee should take up a new agenda item for future meetings, addressing the impact that LEO satellite constellations would have on radio, optical, and infrared astronomy); Moro-Aguilar, *Potential Need*, *supra* note 43, at 501–03 (calling for action in COPUOS subcommittees to address satellite interference with astronomy); Daniel Clery, *Astronomers Stumble in Diplomatic Push to Protect the Night Sky*, SCIENCE INSIDER, (Feb. 27, 2023), https://www.science.org/content/article/astronomers-stumble-diplomatic-push-protect-night-sky (last visited Sept. 24, 2023) [https://perma.cc/X5E3-J2JC] (archived Sept. 29, 2023)(reporting the failure of the Scientific and Technical Subcommittee to agree to establish an expert group with a three-year mandate to study the problem of dark and quiet skies).

spots with favorable breezes, and access to preferred amenities; they will probably spread themselves out accordingly. As other people continue to appear, they, too, will select advantageous venues for their encampments, and the beach may fill up, diminishing the sense of privacy, quiet, and separateness, but still accommodating multiple users. Those who arrived first have no special claim to perpetual preservation of a favored isolation; all must gradually tolerate the noise, chaos, and sheer presence of others; no one can validly claim exclusivity or primacy.

But suppose another kind of user suddenly pops up: a large boisterous crowd that includes numerous, loud, and hyperactive individuals. They set up a pavilion, which blocks the view of the waves for anyone behind them; they delineate a volleyball court, and their vigorous play kicks up sand that flies toward others; they blast raucous music from an enhanced sound system. The local legal ordinances may or may not tolerate these expansive uses, but it is clear that the prior pattern of enjoyment of the beach has been disrupted. Other users might simply relocate as well as they can, but if the whole shoreline has now become sufficiently crowded that there are few good alternative sites for the disgruntled to move into, an unhappy stalemate remains.

Of course, analogies do not constitute proof of anything, and this scenario is perhaps an unfair caricature of aggressive Starlink, OneWeb, and other satellite operators.[211] But the vignette may usefully recap some fundamental questions: Under what circumstances does one set of users of a scarce shared resource acquire a special privilege, which subsequent users must respect (or buy out), and conversely, when do the newcomers have the untrammeled right to do as they like, even if it disrupts and damages their predecessors? What should the legal rules of the game provide, regarding the allocation of permissions among rivalrous players?[212]

---

211. Supporters of the space companies emphasize that their leadership and staff are not just narrow-minded industrialists, but are sincere space enthusiasts, who are supportive of space exploration and use generally, and who share the interest in space science and astronomy. At the same time, the companies' modest attempts at accommodating the observatories have also been characterized as a form of "greenwashing," to claim credit for accommodating environmental interests and signal their virtue. *See* Jonathan O'Callaghan, *SpaceX's Starlink Could Change the Night Sky Forever, and Astronomers Are Not Happy*, FORBES (May 27, 2019), https://www.forbes.com/sites/jonathanocallaghan/2019/05/27/spacexs-starlink-could-change-the-night-sky-forever-and-astronomers-are-not-happy/?sh=2f4cbc4b59b6 [https://perma.cc/6XM3-LZDD] (archived Sept. 29, 2023) (quoting Elon Musk saying, "[W]e'll make sure Starlink has no material effect on discoveries in astronomy. We care a great deal about science." But he also asserts that bringing high-speed internet to the world "is the greater good.").

212. Unlike a beach governed by local ordinances, space is beyond the jurisdiction of any state. Therefore, no single country—even a predominant space power like the United States—could unilaterally compel the others to accept whatever accommodation plan might be developed on a national level.

The world of optical and radio astronomy changed abruptly and massively on May 23, 2019, when the first batch of sixty Starlink satellites was launched. Jolted by the sudden brightness of those spacecraft, and alarmed by the prospect of their legions of successors, observatories scrambled to respond by studying and documenting the true dimensions of the problem, beginning to invent or conceptualize mitigation measures, and entering into discussions with SpaceX and other protagonists. Some astronomers see this as a true "hair on fire" emergency, heralding irretrievable losses to space science; others present a more sanguine face, depicting this as yet another challenge to be surmounted in surveying a decreasingly pristine sky. All agree that the time and the financial costs of conducting effective astronomy will rise significantly and that some important data will simply be irretrievable, with concomitant losses for science and the future exploration and use of space.[213]

In a competition between an abstract desire to observe the universe versus the world's demand for ubiquitous low-latency telecommunications and remote sensing, it may seem appealing to prioritize the LEO satellite constellations.[214] It's hard to argue persuasively against someone who says, "I don't make much use of astronomy in my daily life, but I'm on my cellphone continuously; why should I care if observatories get overshadowed?" Everyone must acknowledge the immense value in extending affordable broadband service to rural and isolated communities worldwide—thereby reducing the digital divide—as well as the value of remote sensing for mapping, land use planning, disaster relief, and climate modeling. But this is not a zero-sum game; there can be mechanisms to share the burdens and opportunities more equitably. And even if astronomy is compelled to recede, it should not be unceremoniously routed in retreat.[215]

---

213. Boyle 2023, *supra* note 45 (observing that astronomers' views are not monolithic, but several express the view that "the sky is falling").

214. Sheen, *supra* note 170 (acknowledging the value of high-speed internet, especially for underserved communities around the world, and particularly when global health challenges have placed a greater emphasis on contactless, online linkages). *But see* 2021 Workshop, *supra* note 2, at 30 (discussing the economic impact of astronomy, noting that in Arizona, astronomy represents a capital investment of $1.3 billion, supports 3300 jobs, and generates an annual economic return to the state of $250 million).

215. SATCON2, *supra* note 2, at 77 (arguing that "Science vs. Internet is a false choice," because affordable broadband is a crucial modern service, "but we must not assume that LEO satellite constellations are the only option, or that sacrificing the night sky is an acceptable trade-off"); SATCON1, *supra* note 6, at 14 (emphasizing that when satellites interfere with astronomy, we will never know what phenomena we will be missing); 2021 CRP, *supra* note 6, at 5 (promoting the concept of "shared stewardship" of space, in which all space stakeholders acknowledge their overlapping responsibilities);

A further comparison to the evolution of domestic US environmental law is apt. In that realm, too, the opportunities for economic development and corporate advancement are important, but they are not automatically dispositive—occasionally, the snail darters do win. More to the point, disputes do not have to be resolved 100 percent in favor of either side; sometimes, careful consideration of alternatives can shed light on effective compromises.[216] ·The 1970 National Environmental Policy Act (NEPA) mandates a careful, deliberative, interdisciplinary study of environmental effects and a "hard look" at mitigations and alternatives.[217] The time has come to revoke the "categorical exclusion" from NEPA mandates that the Federal Communications Commission has applied since 1986 to its licensing of most space activities.[218] Such a reform would not mean

---

Witze, *supra* note 77 (asserting that "the goal is not to pit astronomers against satellite companies, but to develop a vision of how to fairly use the shared realm of outer space.").

216. RUBIN OBSERVATORY, *supra* note 74, at 1 (observing that there is a long history of cooperative international regulation of radio interference via ITU regulations, but there is nothing comparable to deal globally with light pollution; asserting that "Earth orbit is a natural resource without environmental protections, and we are now witnessing the industrialization of this resource by private enterprises"); Rimmer, *supra* note 156 (discussing tradeoffs between incommensurate social values in space, and arguing that commercial interests should not automatically prevail).

217. National Environmental Policy Act of 1969, Pub. L. 91–190, 42 U.S.C. §§ 4321–4347; Baltimore Gas & Electric Co. v. Natural Resources Defense Council, Inc., 462 U.S. 87, 97–100 (1983); Robertson v. Methow Valley Citizens, 490 U.S. 332, 348–353 (1989).

218. FCC 2021 Order, *supra* note 55, at 41–51 (discussing FCC's categorical exclusion of space activities from NEPA and also concluding that a proposed modification of SpaceX's plan for the Starlink constellation did not require preparation of an environmental assessment); FCC 2022 Order, *supra* note 30, at 52–56, 62–65; GAO FCC, *supra* note 176, at 22–28 (describing FCC's traditional use of categorical exemption, and recommending that it be re-examined); SATCON2, *supra* note 2, at 114–15 (arguing that licensing of satellite constellations should not be immune from NEPA), 142–43, 190–92 (noting that other federal agencies like NASA and the Federal Aviation Administration do undertake assessments of the environmental impacts of their space activities), 192–94 (discussing FCC's categorical exclusion of most of its activities from NEPA), 188–95 (discussing the applicability of U.S. environmental law, and federal regulations that direct NEPA's attention to "the human environment"); Ramon J. Ryan, *The Fault in Our Stars: Challenging the FCC's Treatment of Commercial Satellites as Categorically Excluded from Review Under the National Environmental Policy Act*, 22 VAND. J. ENT. TECH. L. 923, 938–947 (2020) (criticizing the FCC's exemption from most NEPA regulation and arguing that it would not be sustained in court; noting that NASA does routinely undertake environmental assessment of its space activities); *see* Jonathan O'Callaghan, *The FCC's Approval of SpaceX's Starlink Mega Constellation May Have Been Unlawful*, SCI. AM. (Jan. 16, 2020), https://www.scientificamerican.com/article/the-fccs-approval-of-spacexs-starlink-mega-constellation-may-have-been-unlawful/ (last visited Sept. 24, 2023) [https://perma.cc/83EN-HG54] (archived Sept. 29, 2023) (discussing FCC's categorical exclusion from NEPA, and whether the agency's space licensing actions "have no significant impact" on the quality of the human environment); FCC Fact Sheet, *supra* note 56 (discussing new FCC regulations regarding minimization of space debris);, 40 CFR § 1508.4 (2022) (defining "categorical exclusion"); 40 CFR § 1508.8 (2020) (including in the definition of environmental "effects" relevant to NEPA

that new satellites—even massive new flotillas—could not be licensed, but it would mean that plans to do so could not proceed in isolation or in disregard of the pernicious, predictable side effects on others in the space ecosystem. Likewise, the other federal agencies engaged in licensing space activities should also regulate more pointedly the light reflectivity and radio noise of Earth-monitoring spacecraft and require adequate, comprehensive environmental assessment prior to launch.[219]

Environmental law and economics also direct our attention to the familiar torts question of "who is the least cost avoider?" More specifically, who could most efficiently make the adjustments that would enable optimal exploitation of the scarce resource by both sets of interests? Phrased differently, why should we not compel the satellite operators to internalize the full costs of their profit-seeking operations, some of which they are currently covertly externalizing and forcing the astronomers to bear?[220]

"aesthetic, cultural, economic, social" effects "whether direct, indirect, or cumulative"); Profit or Safety, *supra* note 11, at 550–52, 552 (concluding that "[s]o far, environmental consequences tend to be weighed inadequately by authorizing governmental authorities [regarding space activities]"); Lawrence, Rawls, Jah, Boley, Vruno, Garrington, Kramer, Lawler, Lowenthal, McDowell & McCaughrean, *supra* note 19, at 429 (making the case for space environmentalism); 2021 Workshop, *supra* note 2, at 25–40 (discussing legal regulation of light pollution), 124 (considering the applicability of environmental law to space as a fourth environment, in addition to land, sea, and air), at 125–28 (considering states' obligations to undertake careful environmental impact assessments); AUGUSTIN CHANOINE, PIERRE-ALEXIS DUVERNOIS & YANNICK LE GUERN, ENVIRONMENTAL IMPACT ASSESSMENT ANALYSIS, TECHNICAL NOTE D8: EXECUTIVE SUMMARY, (July 2017), https://nebula.esa.int/sites/default/files/neb_study/1116/C4000104787ExS.pdf (last visited Sept. 24, 2023) [https://perma.cc/VXA2-6F8A] (archived Sept. 29, 2023) (studying how the European Space Agency could undertake environmental impact assessments for space activities); BEISCHL, *supra* note 42 (calling for greater study of environmental effects of all aspects of satellite megaconstellations); MUDD, *supra* note 209, at 3–5 (calling for FCC to revise its regulations to take environmental factors into account).

219. *See* CHARLES LEE MUDD JR., UNITED NATIONS OFFICE FOR OUTER SPACE AFFAIRS, DARK AND QUIET SKIES FOR SCIENCE AND SOCIETY II, DEFINING AND REGULATING THE ORBITAL ENVIRONMENT OF EARTH 25–38 (Oct. 6, 2021), https://www.unoosa.org/documents/pdf/psa/activities/2021/DQS2021/Day4/Sess14/D4S14_3_SCWG_MUDD_previously_DQS_Quick.pdf (last visited Sept. 24, 2023) [https://perma.cc/24K5-CHHF] (archived 29, 2023) (discussing potential regulation of the Earth's orbital space as part of the environment); BYERS & BOLEY, *supra* note 34, at 99, 108–09.

220. 2021 Workshop, *supra* note 2, at 32, 125 (discussing the "polluter pays" principle, under which environmental harms should be the responsibility of the actor who creates them and who might attempt to externalize that cost); Boley & Lawler, *supra* note 2, at 3–4 (recommending adoption of national policy to address several externalities associated with megaconstellations); Lawrence, Rawls, Jah, Boley, Vruno, Garrington, Kramer, Lawler, Lowenthal, McDowell & McCaughrean, *supra* note 19, at 432 (characterizing LEO satellite harm to astronomy as a "classic example of environmental damage, externalizing true costs.").

We should be careful here to neither overstate nor understate the problem. The large LEO constellations will not completely foreclose ground-based astronomy; most observatories can continue to conduct most of their activities most of the time. As the squadrons of satellites continue to grow inexorably, there will be more streaks across more images, but careful management techniques and improved post-exposure processing can rescue the largest share of the data. On the other hand, the degree of anthropogenic interference encountered to date is but a fraction of what will arise when upwards of 100,000 satellites jostle for position in LEO. The data collection from optical and radio telescopes will be less precise, slower, and more costly, reducing its comprehensiveness and effectiveness. Some valuable observations will be completely missed or misinterpreted and some very costly telescopic infrastructure will be rendered under-productive. For a time-sensitive function such as planetary defense, delaying the discovery of an incoming potentially hazardous asteroid could be disastrous;[221] for deep space science, obscuring discoveries will retard our advancing knowledge of the cosmos. No combination of mitigations will succeed in completely eliminating the interference.[222]

Clearly, it is not sufficient to rely solely on the goodwill and social responsibility of space companies. Even if SpaceX were a model

---

221. Waldek, *supra* note 165 (reporting that interference from LEO satellites can be most problematic for ground-based observatories at twilight, which is an especially important time for planetary defense searches); SATCON2, *supra* note 2, at 147 (emphasizing the potential adverse consequences if planetary defense observations are inhibited); 2021 Workshop, *supra* note 2, at 121–22 (explaining that the presence of large LEO satellite constellations will not preclude planetary defense mechanisms from operating, but could cause delays in detecting and identifying a threatening space object, which could decrease the time available for an effective response); NASA FCC Letter, *supra* note 30, at 3 (estimating that "there would be a Starlink in every single asteroid survey image taken for planetary defense against hazardous asteroid impacts, decreasing asteroid survey effectiveness…and could have a detrimental effect on our planet's ability to detect and possibly redirect a potentially catastrophic impact."); NATIONAL ACADEMIES OF SCIENCE, ENGINEERING, AND MEDICINE, ORIGINS, WORLDS, AND LIFE: A DECADAL STRATEGY FOR PLANETARY SCIENCE AND ASTROBIOLOGY 2023-2032 18–8 (WASH. D.C.: THE NATIONAL ACADEMIES PRESS 2022) (assessing that satellite megaconstellations "are contaminating a fraction of each night's survey" of asteroids, "making it more difficult to detect potentially hazardous objects" and concluding that "no combination of even "best-case" mitigation measures . . . will be capable of fully countering the constellations' negative impact").

222. SATCON1, *supra* note 6, at 3; Technology Assessment, *supra* note 10, at 26; Profit or Safety, *supra* note 11, at 547 (also suggesting that the OST affords scientific exploration a priority over other space activities); Waldek, *supra* note 165; Apollo Academic Surveys, *supra* note 165(reporting widely varying views of planetary defense astronomers regarding LEO megaconstellation interference, with all voicing some degree of concern about the situation, but some expressing confidence that mitigation measures can suffice and others foreseeing insoluble problems); BYERS & BOLEY, *supra* note 34, at 109 (concluding that both astronomy and satellite megaconstellations constitute legitimate uses of space, and neither can absolutely impede the other; instead, there must be a balance, although there is currently no consensus on how that balance should be struck).

corporate citizen, attempting in all good faith and at its own expense to find agreeable solutions to mitigate the excessive sound and light associated with Starlink, that is not a dependable formula. Any voluntary accommodations could be reversed (as, indeed, they have been); other companies and other countries may not voluntarily mimic the leader's best practices.[223] The force of international and domestic law will be necessary, sooner or later, to make a compromise reliable.[224]

In sum, this is a story about two socially valuable activities; there are no villains in this drama, and both sides were surprised by their emergent conflict. But the two virtues do compete; they do overlap at least partially, and one of them is becoming overwhelmed. It is not effete to care so much about astronomy, and it is not hysterical to demand immediate corrective action. The world needs to act thoughtfully and vigorously, rebalancing social priorities and costs before it is too late[225] and global astronomy becomes "blinded by the light."[226]

---

223. Jonathan O'Callaghan, *SpaceX Starlink Mega Constellation Faces Fresh Legal Challenge*, SCI. AM. (June 15, 2021), https://www.scientificamerican.com/article/spacex-starlink-mega-constellation-faces-fresh-legal-challenge/ [https://perma.cc/5VG5-JFTM] (archived Sept. 29, 2023) (noting that the operators of large constellations other than SpaceX, such as Lynk, Amazon, and the government of China, have not undertaken mitigation activities and have not indicated an intention to do so); Tyson, *supra* note 60, at 11 (observing that there is no guarantee that other LEO satellite operators will follow Starlink's [now discontinued] practice of darkening its satellites); White Paper, *supra* note 50, at 9 (SpaceX "will continue to work closely with the astronomy community to mitigate the effect of all satellite operations on their important work"); Witze, *supra* note 77 (indicating that OneWeb and Amazon have engaged in conversations with the astronomical community about reducing satellite brightness); Hall, *supra* note 171 (quoting astronomer Megan Donohue saying "It's more of a philosophical question. It kind of boils down to: How much do I trust corporate good will, and how much would a corporation care about the opinion of people who care about science and astronomy?"); Rotola & Williams, *supra* note 97, at 547; William Wilson Bratton, *Never Trust a Corporation,* 70 GEO. WASH. L. R. 867, 867 (2002) (arguing that the inherent nature of the corporate structure and incentives means that business entities cannot be relied upon to exercise corporate social responsibility on a sustained, consistent basis).

224. *See* Strategic Framework, *supra* note 33, at 20 (emphasizing the importance of a "rules-based international order for outer space activities," and committing the United States to "build international partnerships for civil and national security space").

225. SATCON2, *supra* note 2, at 76 (citing historical mistakes regarding disruptive technologies that were developed and deployed first and regulated only later).

226. BRUCE SPRINGSTEEN, BLINDED BY THE LIGHT (Columbia Records 1973).